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Evaluation of Hydraulic and Hydrochemical Aspects of Proposed Bulkheads Sunnyside Mine San Juan County, Colorado

March 12, 1993

Prepared for:

Sunnyside Gold Corporation

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1.0 EXECUTIVE SUMMARY

The Sunnyside Mine is located approximately 8 miles north of Silverton, Colorado, in northernmost San Juan County. Slightly acidic water with mobilized heavy metals flows from both access tunnels to the mine. Sunnyside Gold Corporation (SGC) proposes to install underground bulkheads in order to contain mine drainage and allow a return to an approximation of pre-mine hydrologic conditions. This report estimates the influence that local hydrogeology will have on the effectiveness of the proposed bulkheads, the impact that the proposed bulkheads will have on the ground-water flow system, and the probable effects that installing the proposed bulkheads will have on the hydrochemistry of ground water and surface water in the vicinity of the Sunnyside Mine.

In the vicinity of the Sunnyside Mine, ground water moves through fractures. Permeability in the area is anisotropic, with greater permeability in a northeast/southwest direction due to the dominant fracture orientation in the Eureka graben. The original direction of ground water movement appears to have been from the Sunnyside Basin (where the Sunnyside Mine workings are) towards Cement Creek. The original ground-water flow direction is expected to eventually be reestablished if the proposed bulkheads are installed.

Flow testing of boreholes in the American Tunnel yielded an estimated hydraulic conductivity of $5x10^{-5}$ cm/sec (0.15 feet/day). However, rock in the vicinity of the flow tests exhibits more fracture permeability than is typical for the American Tunnel, so this estimated hydraulic conductivity may be higher than the general average. Laboratory measurement of intergranular hydraulic conductivities of core from proposed bulkhead sites showed a range from 10^{-8} to 10^{-10} cm/sec. Laboratory measurement of two fractured cores, which appear to represent local blast damage, showed hydraulic conductivity on the order of 10^{-6} cm/sec.

The Sunnyside Mine workings are expected to fill with water until an equilibrium is reached between water flowing into the mine workings and water leaving the mine workings via natural fracture pathways. Based on historical information the equilibrium water level is expected to be approximately at F level (11,500 feet msl). Once a bulkhead is installed in the American Tunnel, it is estimated that the water level will substantially reach equilibrium (86% of equilibrium) in approximately 10 years.

The rate of leakage through the bedrock in the immediate vicinity of each proposed bulkhead is expected to be less than 1 gpm. However, if the permeability and equilibrium water level are both higher than anticipated, such leakage through the bedrock could be as much as 25 gpm.

The overall, generalized flow through the flooded mine workings to the surface along natural fractures is expected to be approximately 70 gpm, but could be as great as 200 gpm. The discharge to the surface is expected to occur primarily along Cement Creek between the Mogul Mine (to the north) and the Silver Ledge Mine (on the south). The discharge is expected to be diffuse rather than concentrated at one spring. However, if the equilibrium water level in the flooded mine workings is much higher than anticipated (12,250 feet msl), up to an additional 160 gpm could discharge via the Mogul Mine. The travel time from the flooded workings to Cement Creek is estimated at approximately 150 years. Under the unlikely scenario that the equilibrium water level in the flooded workings is at 12,250 feet msl, some of the water could reach Cement Creek in as little as 4 months.

The computer program MINTEQA2 was used to model the geochemistry of the rock-water reactions that are expected to result from the proposed bulkhead installations. At the American Tunnel bulkhead, the model indicates water is non-reactive with the country rock. The water behind the Terry Tunnel bulkhead is expected to be similar to the water currently discharging there. Reaction with the country rock should be minimal and will probably decrease matrix permeability with time.

In the absence of the ability to significantly oxygenate the flooded mine, the mineral load of the impounded water should be essentially that of the water that fills the mine.

basis.

This water, once equilibrated with mine minerals, is not expected to react further with vein minerals or country rock as it migrates laterally to discharge at the surface.

The modeled waters, upon discharge at the surface, will equilibrate with atmospheric carbon dioxide and oxygen. The greatest chemical change to the system will be that of changing from reduced (subsurface) waters to oxygenated (surface) waters. Oxides of most of the metals are less soluble than are the minerals associated with reduced species and most of the mineral load will be precipitated from the water. This is analogous to the process which formed the natural iron "bogs" in the area. Using conservative assumptions, the installation of these bulkheads is expected to deliver the following metals load (lbs/day) to Cement Creek: iron, <.1; manganese, <.1; zinc, 8.1 to 20.3; cadmium, .009 to .036; lead, .16 to .40; and copper, .22 to .23.

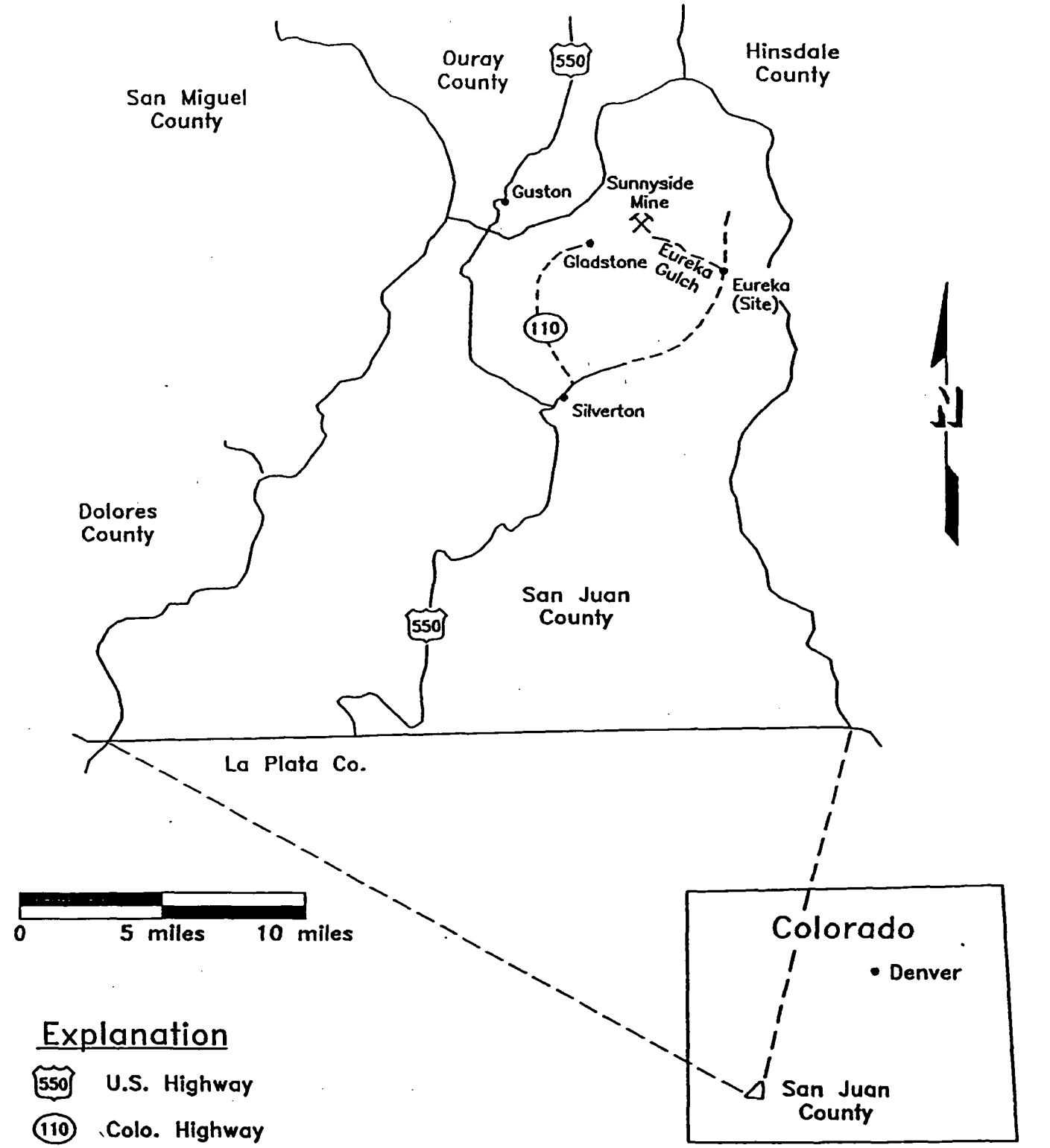
2.0 INTRODUCTION

2.1 Location and Brief Description of the Sunnyside Mine

The Sunnyside Mine is located approximately 8 miles north of Silverton in the Eureka mining district in northernmost San Juan County, Colorado (Figure 1). The Sunnyside Mine is presently owned by Sunnyside Gold Corporation (SGC), a subsidiary of Echo Bay Mines. Gold, silver, copper, lead, zinc, and cadmium ores have been produced from more than 150 miles of underground workings with a vertical extent of 2,000 feet. The majority of the mine workings are located beneath Sunnyside Basin at the head of Eureka Gulch (Figure 2). Year-round access to the main part of the mine is via the 10,000 foot long American Tunnel, the portal of which is located at an elevation of 10,617 feet at the abandoned townsite of Gladstone. Secondary access is via the Terry Tunnel located in Eureka Gulch at an elevation of approximately 11,560 feet. The jeep trail to the Terry Tunnel is impassible during winter and spring.

2.2 Statement of the Problem

Sunnyside Gold Corporation is working toward closing the Sunnyside Mine with a goal of reclaiming the mine property and reestablishing an approximation of the pre-mining hydrogeologic system. As a part of this process SGC proposes to install underground bulkheads in at least four locations in order to contain mine drainage. Drainage from the Sunnyside Mine, which presently flows out of both the American Tunnel and the Terry Tunnel, is slightly acidic and contains mobilized heavy metals (Simon Hydro-



Sunnyside Gold Corporation San Juan County, Colorado	DATE: 10/7/91 DRAWN: KE CHECKED: APPROVED: DWG NO: PROJ.: 46411036
Location of the Sunnyside Mine	
Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine	Figure

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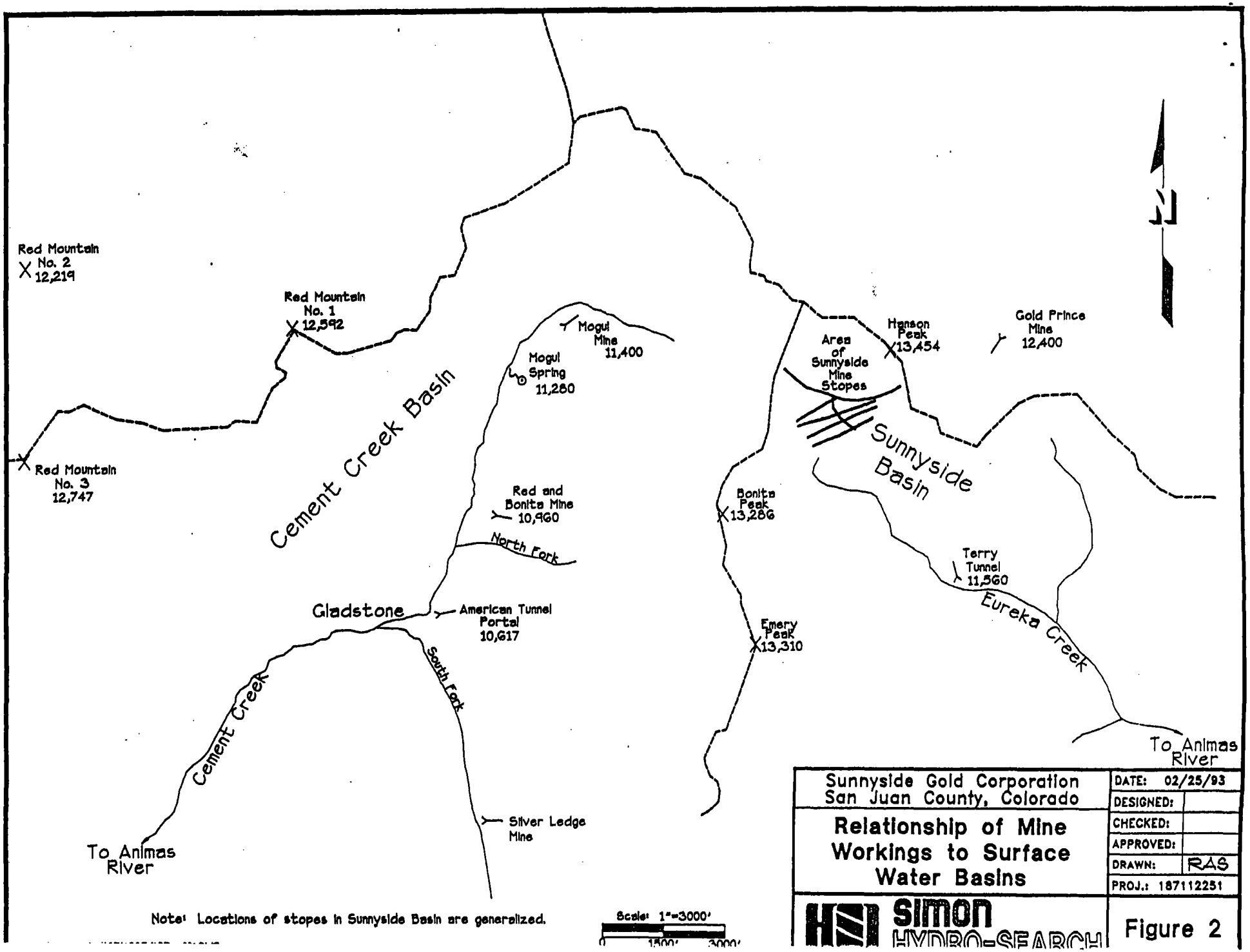

Red Mountain No. 2 12,219
Red Mountain No. 1 12,592
Red Mountain No. 3 12,747
Cement Creek Basin
Mogul Mine 11,400
Mogul Spring 11,280
Red and Bonita Mine 10,960
North Fork
Gladstone
American Tunnel Portal 10,617
South Fork
Cement Creek
To Animas River
Silver Ledge Mine
Area of Sunnyside Mine Stopes
Hanson Peak 13,454
Gold Prince Mine 12,400
Sunnyside Basin
Bonita Peak 13,286
Terry Tunnel 11,560
Eureka Creek
Emery Peak 13,310
To Animas River
N
Note: Locations of stopes in Sunnyside Basin are generalized.
Scale: 1"=3000'
0
1500'
3000'
Sunnyside Gold Corporation
San Juan County, Colorado
Relationship of Mine Workings to Surface Water Basins
DATE: 02/25/93
DESIGNED:
CHECKED:
APPROVED:
DRAWN: RAS
PROJ.: 187112251
SIMON HYDRO-SEARCH
Figure 2

Search, 1992). The bulkheads proposed by SGC are intended to return the ground-water system to an approximation of the flow regime which existed under natural, pre-mining, conditions.

2.3 Reports Prepared to Evaluate Impacts of Proposed Bulkheads at the Sunnyside Mine

This report estimates the influence that local hydrogeology will have on the effectiveness of the proposed bulkheads, and the impact that the proposed bulkheads will have on the ground-water flow system in the vicinity of the Sunnyside Mine. Also considered are the probable effects that installing the proposed underground bulkheads will have on the chemistry of ground water and surface water. Two other reports have been prepared to date which pertain to other aspects of the proposed bulkheads. An assessment of the natural (pre-mining) hydrologic system and present hydrology was given in "Preliminary Characterization of the Hydrology and Water Chemistry of the Sunnyside Mine and Vicinity, San Juan County, Colorado" dated February 11, 1992 by Simon Hydro-Search. Engineering aspects of the proposed bulkheads, including mechanical strength of the bulkheads and adjacent wall rock, and the chemical and physical integrity of the bulkheads, were addressed in "Bulkhead Design for the Sunnyside Mine, Sunnyside Gold Corp., An Echo Bay Company" by Dr. John F. Abel, Jr., PE.

2.4 *Purpose and Scope*

The purpose of this report is to assess the hydrogeologic and hydrochemical aspects of the proposed underground bulkheads. Specifically this report addresses:

- the likely rate of leakage in the immediate vicinity of the bulkheads;
- the anticipated equilibrium water level in the flooded mine workings;
- the approximate rate at which the mine workings will fill with water;
- the nature, rate, and timing of movement of water from flooded workings to the surface along natural and man-made pathways;
- the likely chemistry of water which would be impounded;
- the expected reactions between impounded water and country rock and mineralized veins; and
- the effects of the proposed bulkheads on the chemistry of local surface water.

This report builds upon an understanding gained during preparation of the earlier report, "Preliminary Characterization of the Hydrology and Water Chemistry of the Sunnyside Mine and Vicinity, San Juan County, Colorado" (Simon Hydro-Search, 1992). Additional work conducted in support of this report included:

- Field examinations of proposed bulkhead sites in the American Tunnel, Terry Tunnel, F-Level Brenneman vein, and B-Level Brenneman vein;
- Conducting flow tests from boreholes in the American Tunnel in order to estimate the hydraulic conductivity of the fractured volcanic rocks;
- Laboratory measurement of permeability of rock cores taken from proposed bulkhead locations;
- Detailed calculation of the volume of mine workings (in vertical increments of 100 feet) for use in estimating flooding rates;
- Simple numerical modeling of the rate of mine flooding;
- A detailed analysis of the data to estimate hydraulic aspects of the proposed bulkheads;
- Petrographic analysis of wall rock from the vicinity of proposed bulkheads;
- Collection of secondary mineralization (wall encrustations) and subsequent testing for acid-generating capacity;
- Geochemical modeling of water/rock interactions using the MINTEQA2 code; and
- A detailed analysis of water chemistry and mineralogic data to estimate the hydrochemical impacts of the proposed bulkheads.

3.0 GENERAL HYDROGEOLOGY OF THE SUNNYSIDE MINE

The general hydrogeology in the vicinity of the Sunnyside Mine was covered in "Preliminary Characterization of the Hydrology and Water Chemistry of the Sunnyside Mine and Vicinity, San Juan County, Colorado" by Simon Hydro-Search (1992). Selected aspects of that discussion are excerpted below.

3.1 Geology Pertinent to Ground-Water Flow and Chemistry

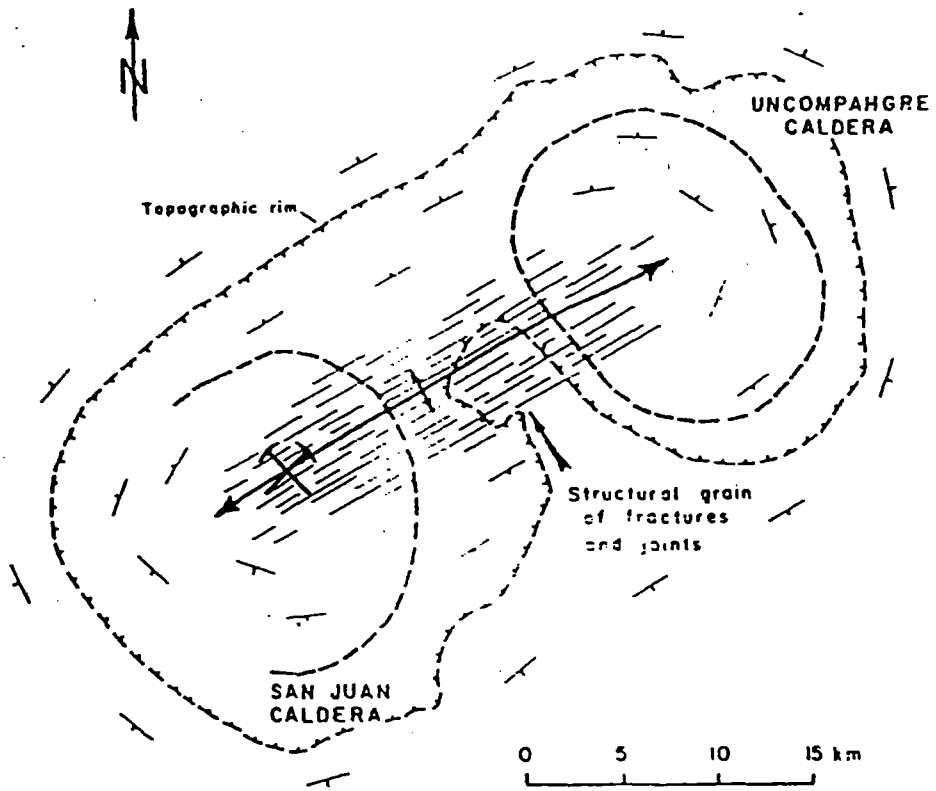
Rocks in the vicinity of the Sunnyside Mine are pyroclastics and flows which erupted from local calderas approximately 28 million years ago (Steven and Lipman, 1976). The Sunnyside Mine is principally located within the Burns Formation, which generally consists of massive silica-rich latite flows which have locally been altered and mineralized (Langston, pp. 34-39). The highest mine workings (above A level) extend into the overlying interbedded lava flows and air-fall tuffs of the Henson Formation, an alkali-rich andesite (Langston, p. 49).

The Burns Formation was erupted from vents within the San Juan caldera (Steven and Lipman, 1976, p. 11-12). The degree of welding of the upper Burns formation generally increases towards the west in the direction of the vent source (Langston, 1978, p. 11). The Henson Formation also was derived from vents located within the San Juan caldera, but typically is less welded than the Burns Formation and contains more pyroclastic units.

The extent of fracturing in volcanic rocks is directly related to the degree of welding if other factors are equal. Hence, the more welded Burns Formation tends to be more fractured than the Henson Formation.

After the deposition of the Burns and Henson formations there was a broad resurgent doming between the San Juan caldera and the Uncompahgre caldera. This resurgent doming resulted in extensive distension fracturing in a northeast/southwest-trending direction (Steven and Lipman, 1976, p. 13) as shown in Figure 3. Later collapse of the resurgent doming along steeply dipping, northeast/southwest-trending fractures formed the Eureka graben. Arcuate faults related to the collapse of the Silverton caldera (such as the Bonita fault) appear to be contemporaneous with the bounding faults of the Eureka graben. Although some later faulting exists, the Eureka graben fracture system was the last major set of fractures imprinted on the area of the Sunnyside Mine. During mineralization 13.0 to 16.6 MYBP (Casadevall and Ohmoto, 1977), the fractures of this system served as flow conduits and sites for ore deposition.

The Sunnyside Mine is located within the Eureka graben at the junction of the Ross Basin fault and the Sunnyside fault as shown in Figure 4. Figure 4 also illustrates the dominant northeast/southwest fracture trend. In the vicinity of the mine, the dip of originally horizontal strata now ranges from 10° to 14° to the southwest (Langston, 1978, p. 17).



Present location of Sunnyside Mine

Approximate Axis of Resurgent Doming

Trend of Distension Fracture

Taken from Langston, 1978

San Juan County Mining Venture Silverton, Colorado	DATE: 10/10/ DRAWN: KE CHECKED: APPROVED: DWG NO: PROJ.: 464110
Dominant Fracture System of the San Juan Caldera	
Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS Reno Denver Milwaukee Irvine	Figure

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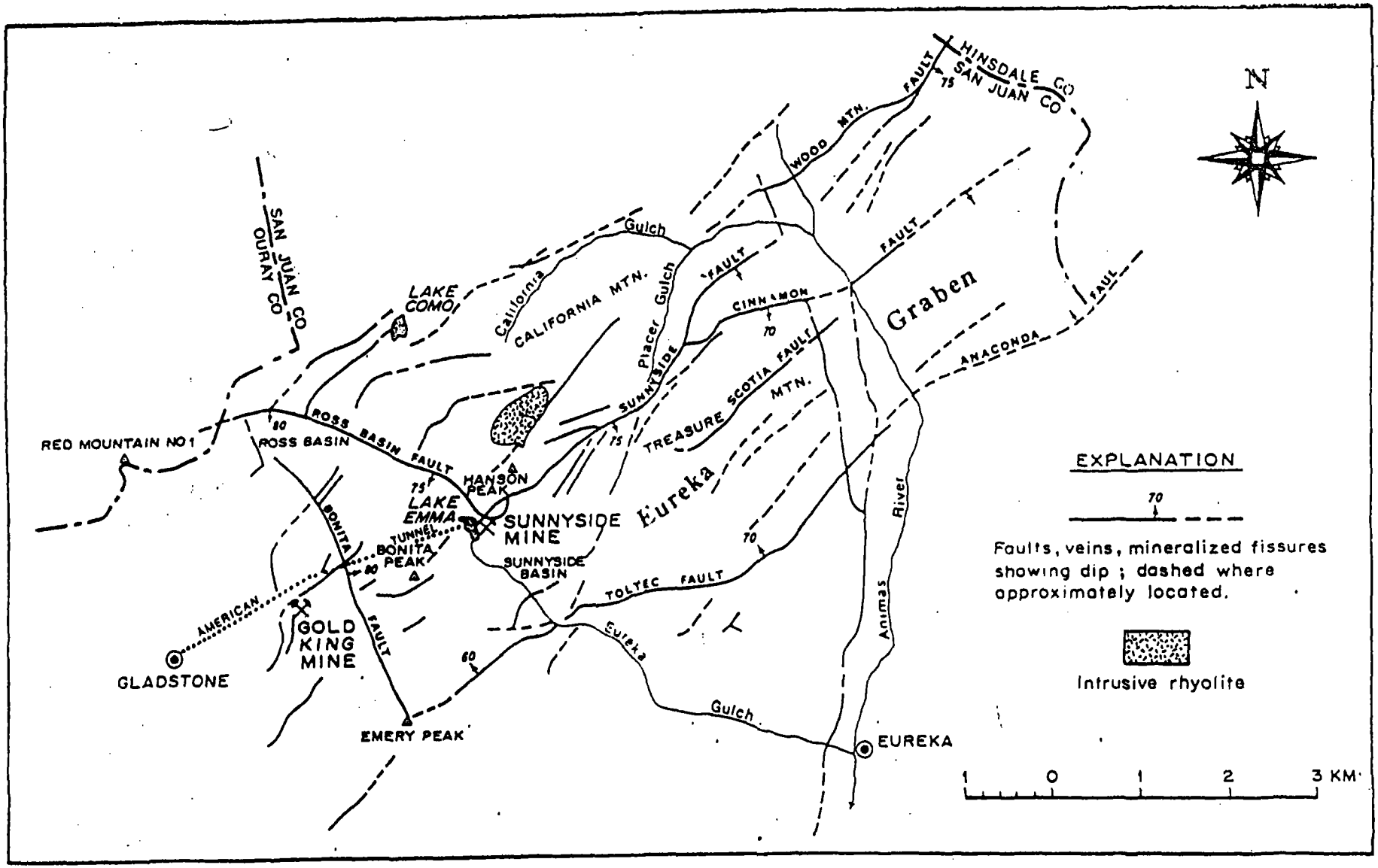


San Juan County Mining Venture Silverton, Colorado	DATE: 10/10/91 DRAWN: KEK
Structural Geology in the Vicinity of the Sunnyside Mine, San Juan County, Co.	CHECKED: APPROVED: DWG NO: PROJ.: 464110381
Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS	Figure 4

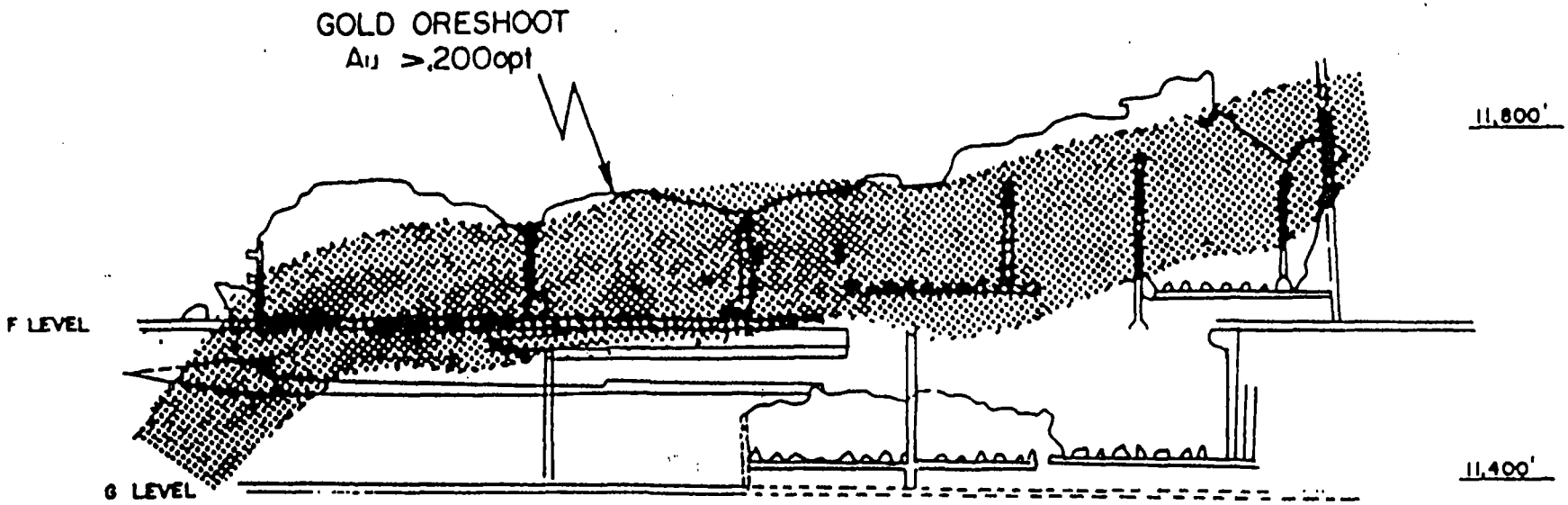
Rock alteration and mineralization is widespread in the vicinity of the San Juan caldera. "Propylitic alteration has affected many cubic miles of volcanic rocks throughout and beyond the [Silverton] caldera" (Burbank, 1960). In the propylitized rocks "pyrite is ubiquitous and forms between 0.1 and 2.0 percent" of the rock volume (Casadevall and Ohmoto, 1977, p. 1292). In excess of one billion tons of pyrite are estimated to exist in rocks in the vicinity of the Sunnyside Mine (assuming 5 cubic miles of propylitized rocks with 1.0% pyrite). The weathering of this dispersed pyrite as well as other mineralization has resulted in the pervasive staining which is common in rocks throughout the area (e.g. Red Mountains 1, 2, and 3).

3.2 Bedrock Permeability

Fracture permeability in the vicinity of the Sunnyside Mine is anisotropic. Permeability is greater in a northeast/southwest direction due to the dominant fracture orientation within the Eureka graben. In addition, fracture permeability is greater in the welded tuffs and flows than in the unwelded units. The southwest dip in the vicinity of the mine results in zones of greater permeability which dip southwest along the more highly fractured units. The overall effect is that the greatest permeability zones trend northeast/southwest and dip about 10° - 14° southwest. Field evidence for this anisotropy in permeability includes a preferred orientation for ore shoots. Figure 5 shows an example of a northeast/southwest trending ore shoot which dips southwest.

SOUTHWEST

NORTHEAST



LONGITUDINAL CROSS-SECTION

2150 VEIN

0 SCALE IN FEET 400'

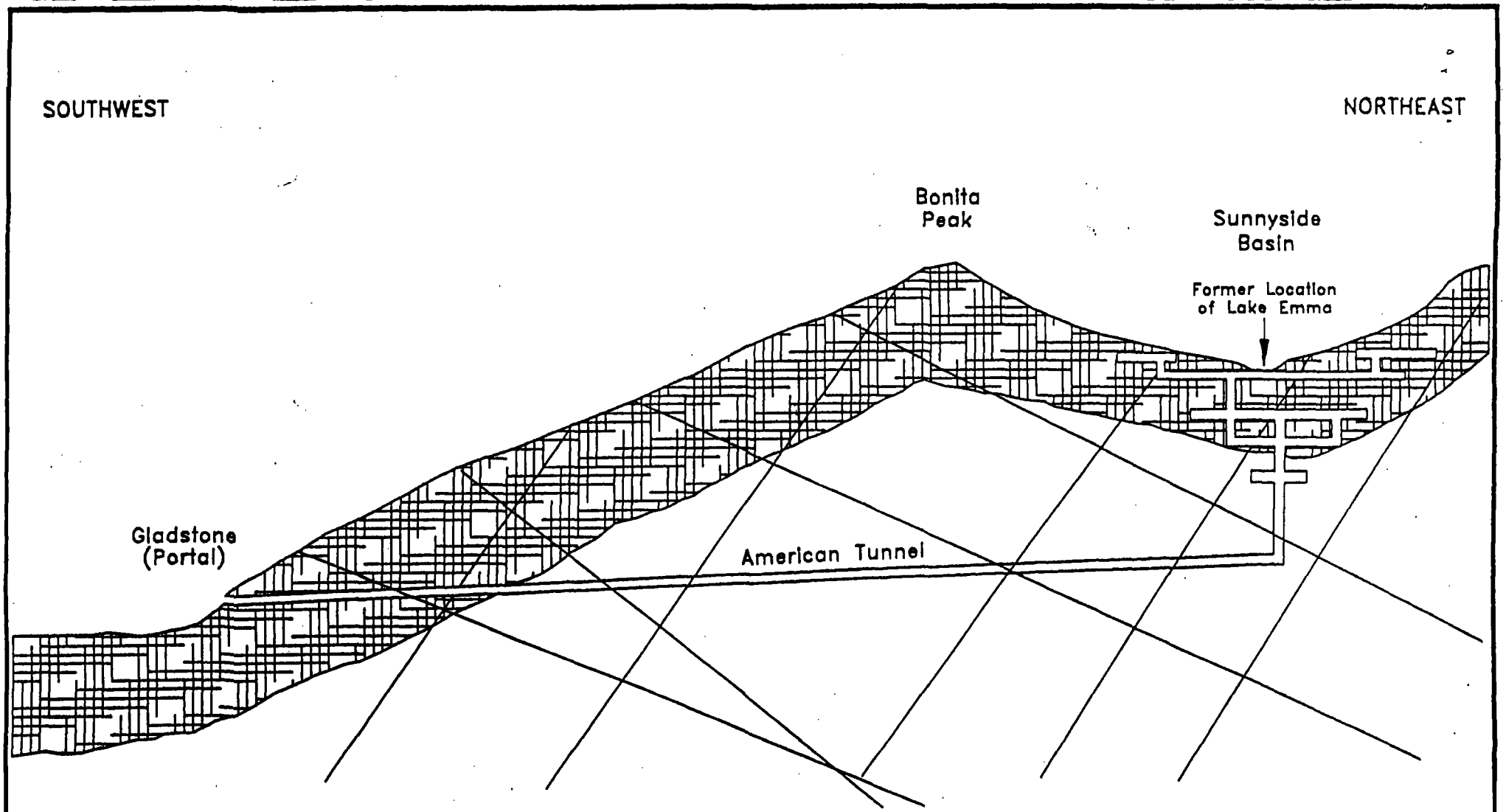
San Juan County Mining Venture Silverton, Colorado	DATE: 10/21/91 DRAWN: KEK
A Southwest Raking Ore Shoot on the 2150 Vein Sunnyside Mine	CHECKED: APPROVED: DWG NO: PROJ.: 464110381
Hydro-Search, Inc.	Figure 5

Figure from Sunnyside Gold

Fracture permeability generally decreases with depth as the fractures are made progressively tighter by increasing overburden pressure. Evidence for this can be observed in both the American Tunnel and the Terry Tunnel. At locations deep within the mine, water enters each tunnel only where major fractures are encountered, and most of the back and rib of the tunnel is dry. However, as the portals are approached decreasing overburden pressure allows relatively minor joints to transmit water and dripping water becomes common.

In the deeper parts of the flow system, significant quantities of water are transmitted only by major fractures. This is demonstrated by the fact that the deeper part of the present American Tunnel (beyond the Daylight Corner at approximately 2700 feet from the outside end of track[1]) has intercepted 1350 gpm of ground water. Of this 1350 gpm, 90 percent can be accounted for from the intersection of five major fracture zones (the Washington vein, the Sunnyside vein, the Brenneman vein, a fracture zone at the 0700 runaround, and a fracture zone located 3020 to 3220 feet from the end of track (see section 4.2.1). Figure 6 is a schematic diagram showing the manner in which fracture permeability changes with depth.

[1] All footages along the American Tunnel are referenced to track repair footages as marked on the tunnel wall. The track repair footages have a zero point just outside of the portal.



EXPLANATION

Zone where minor fractures transmit significant quantities of water.

Major fractures which transmit water even under considerable overburden pressure.

Mine workings.

NOT TO SCALE

San Juan County Mining Venture Silverton, Colorado	DATE: 10/23/91 DRAWN: DRD CHECKED: APPROVED:
Schematic of Differing Fracture Permeability With Depth	DWG NO: PROJ.: 464110381
Hydro-Search, Inc. HYDROLOGISTS-GEOLOGISTS-ENGINEERS	Figure 6

3.3 Pre-Mining Potentiometric Surface

Simon Hydro-Search has used observations from 1959 and 1961 to estimate the equilibrium static water level beneath the Sunnyside Basin. Mr. Bob Ward (mine superintendent during construction of the American Tunnel) personally saw that the static water level in the Washington Inclined Shaft was approximately 50 feet below F level during the summer of 1959. Mr. Ward's recollection appears reasonable in light of a letter from D. Hutchinson to Messrs. William R. McCormick and Robert M. Hurst dated February 3, 1961. This letter states that during January of 1961 (after the American Tunnel had intersected some of the fractures under the old workings) "the water was 97 feet below F level and falling 3½ feet per day". The observed water levels in 1959 and 1961 were below F level where drainage to the surface would have occurred via the Terry Tunnel. The 1959 static water level reflects a lack of dewatering during the preceding 20-year period during which time the mine was inactive. The 1959 static water level is thought to represent an equilibrium condition of inflow to the workings versus outflow via natural fracture permeability. It is worth noting that this static water level is deep enough that most of the minor joints would be closed by the overburden pressure.

Direct surface-water inflow to the mine in 1959 was far less than in 1992. Hence, the static water level in 1959, estimated at 11,500 feet above mean sea level (msl), is assumed to approximate the static water level in the fractured bedrock prior to commencing mining.

Lake Emma was a glacial tarn in Sunnyside Basin at an elevation of approximately 12,250 feet msl. On June 4, 1978 Lake Emma drained into workings on the Spur vein causing massive damage throughout the mine (Bird, 1986, p. 135). In areas of high permeability a lake can usually be considered to represent the water table. However, this does not appear to have been the case for Lake Emma. Two samples of the lacustrine clays which formerly were under Lake Emma were tested in August 1988 and shown to have permeabilities ranging from 1.6×10^{-7} to 6.7×10^{-9} cm/sec under 95% relative compaction. These permeability values are very low and little water would have been transmitted through such material. Lake Emma is considered to have been perched on low permeability lacustrine clays.

3.4 Pre-Mining Direction of Ground-Water Flow

Prior to the existence of the mine, the gradient was approximately 0.1 feet/foot from the head of Sunnyside Basin to either Cement Creek, at Gladstone, or to the Animas River at the site of Eureka (see Table 1). If the pre-mine hydraulic head under Sunnyside Basin had been higher or lower the hydraulic gradient would have a different value, but the rate of change in gradient would be about the same to the southeast (toward Midway Mill site) as to the southwest (toward Gladstone).

Table 1. Estimated Pre-Mine Ground-Water Gradient within the Fractured Bedrock

	Elevation[1] (feet msl)	Distance[1] from Workings under Sunnyside Basin (feet)	Gradient[2] from head of Sunnyside Basin to indicated point
Cement Creek near Portal of American Tunnel	10,500	9,500	0.105
Discharge Zone near Mogul Mine Portal	11,250	6,300	0.040
Animas River at Site of Eureka	9,850	15,600	0.106
Eureka Gulch near Midway Mill Site	10,480	9,300	0.110

1) Estimated from U.S.G.S. Handies Peak and Ironton 7 1/2 minute quadrangles

2) Assumes the pre-mine hydraulic head in the fractured bedrock beneath Lake Emma was approximately 11,500 feet above mean sea level (based on the 1959 water-level observation of Mr. Bob Ward).

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If permeability had been homogeneous and isotropic, the groundwater would have moved in both directions. However, a strong anisotropy exists with enhanced permeability both in a northeast/southwest direction and also dipping southwest. In addition, greater fracture permeability associated with a higher degree of welding of the volcanics is expected beneath the Gladstone area than beneath the Sunnyside basin. The local anisotropy and inhomogeneity of the fracture permeability would facilitate ground-water movement toward Cement Creek. Hence, the majority of water in the bedrock flow system is inferred to have moved from the Sunnyside Basin to the Cement Creek drainage where it discharged as springs and seeps.

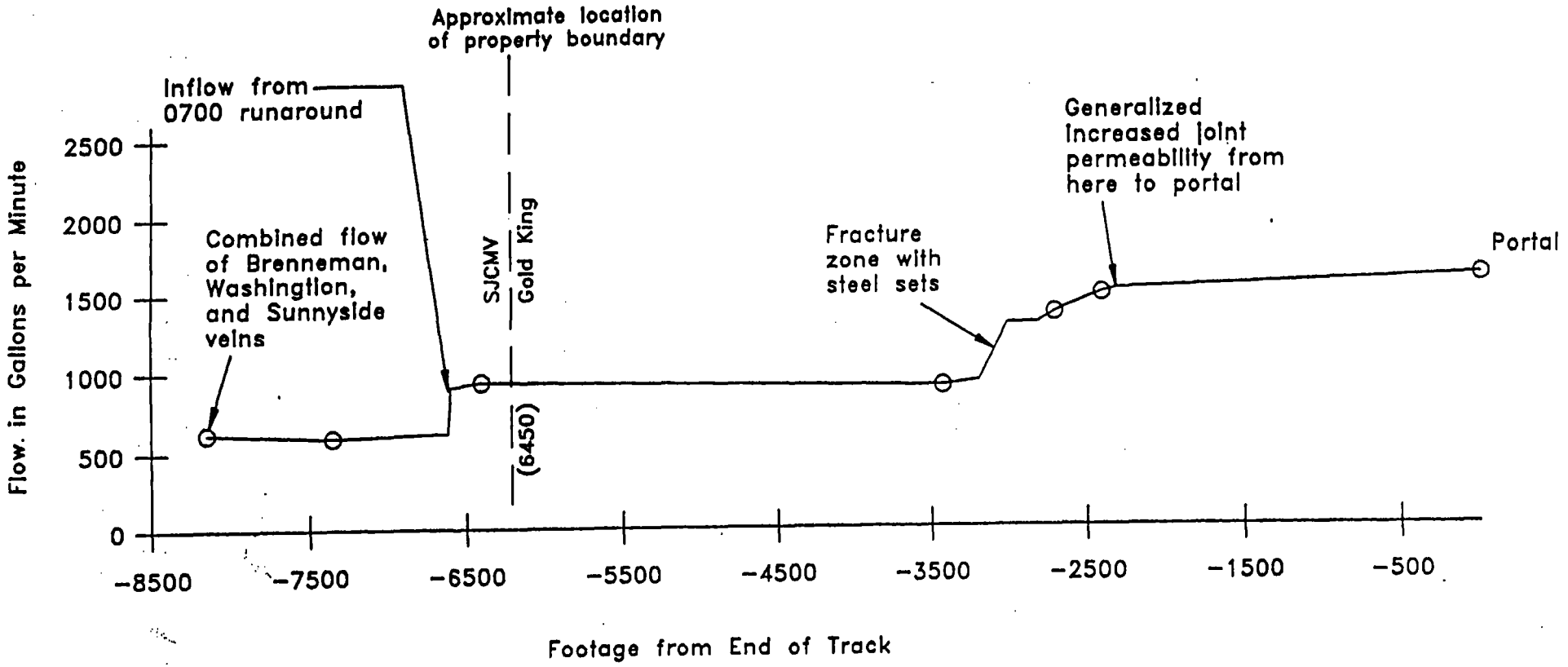
Field evidence supports the idea that the preferred ground-water flow direction is southwest rather than southeast in the vicinity of the Sunnyside Mine. Field observations by Simon Hydro-Search staff during July and August, 1991 located a greater number of visible springs and seeps in the Cement Creek drainage, above Gladstone, than in Eureka Gulch. Furthermore, the springs and seeps in the two forks of Cement Creek above Gladstone are preferentially located on the east side of the creek, indicating a source to the east is most likely. Finally, based on the volume of dumps, the Silver Ledge Mine, located on the east side of the South Fork of Cement Creek, appears to have approximately the same extent of underground workings as the Big Colorado Mine located directly across the creek. Yet, based on the present flow from the portals, the Silver Ledge Mine intercepted approximately ten times as much water as the Big Colorado Mine.

4.0 HYDROLOGY AFTER PROPOSED BULKHEADS ARE INSTALLED

This section outlines the overall hydrologic situation which is expected to result from the installation of underground bulkheads proposed by SGC. Many of the details and supporting evidence for this conceptual hydrologic model are provided in the following sections.

Once the bulkhead is installed in the American Tunnel (near the underground property line with the Gold King Mine) waters presently leaving the Sunnyside Gold property are expected to be impounded behind the bulkhead. The physical and chemical integrity of the bulkhead itself are considered in a separate report by Abel, 1993. The rate of localized leakage around the bulkhead is considered in Section 7.3 of this report.

It should be noted that the proposed bulkhead near the underground property line is expected to impound the water which originates on SGC property, but a significant amount of water originating on Gold King property will not be impounded. Figure 7 shows that approximately 930 gpm presently flows past the proposed American Tunnel bulkhead site, but that approximately an additional 650 gpm flows into the American Tunnel from Gold King property. Hence, the American Tunnel portal is expected to flow an average of approximately 650 gpm even after installation of the proposed bulkhead. The rate of flow downstream of the proposed American Tunnel



EXPLANATION

○ Flow Measurement Points

NOTES

1. Footages are distance from end of track as marked on the wall of the American Tunnel and are approximate. The end of track is just outside of the American Tunnel portal.

2. Flow at all points except portal was measured with a pygmy flow meter by Evelyn Bingham and Guy Lewis of SJCMV on October 2–3, 1991. Portal flow represents an average of flume measurements.

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Flow Profile Along the American Tunnel	
SIMON HYDRO-SEARCH	Figure 7

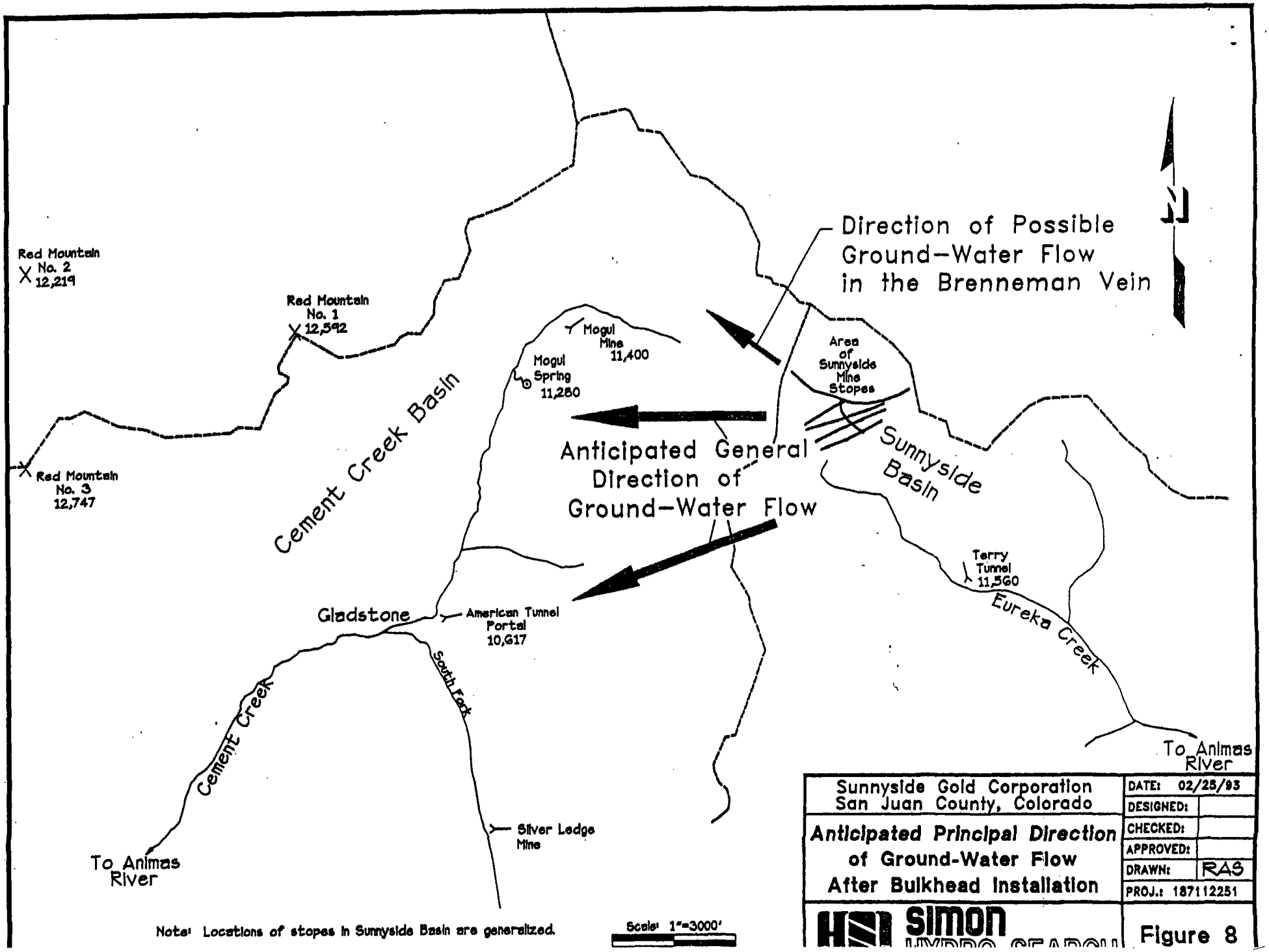
bulkhead site is not expected to increase substantially after bulkhead construction because no significantly permeable fractures have been observed for the next 3000 feet downstream.

The Sunnyside Mine workings are expected to fill with water until an equilibrium is reached between water flowing into the mine workings and water leaving the mine workings via natural fracture pathways. If the ongoing reclamation work in Sunnyside Basin is successful in diverting surface water from entering underground workings, then the equilibrium water level in the flooded mine workings is expected to be just below F-level at approximately 11,500 feet msl (see Sections 3.3 and 7.1 for details). If surface water inflow to the mine is not substantially decreased, then the equilibrium water level may be correspondingly higher. The absolute maximum possible equilibrium water level is at the elevation of land surface in the Sunnyside Basin (approximately 12,250 feet msl).

Although equilibrium water level in the flooded workings is expected to be just below F-level, three additional bulkhead locations have been proposed by SGC to impound water in case it rises as high as the land surface in Sunnyside Basin. A proposed bulkhead in the Terry Tunnel is intended to keep water from flowing out of the Terry Tunnel portal. Two sets of proposed bulkheads on the Brenneman vein, one set on F-level and one set on B-level (at approximately 12,150 feet) are intended to keep water from flowing into the Mogul Mine. Although only one tunnel connects the

Sunnyside and Mogul mines (at an elevation of 11,904 feet msl), access to that tunnel is so difficult that it is more convenient to place two sets of bulkheads at locations before the workings converge to a single tunnel. There also exists a connection between the Sunnyside Mine and the Gold Prince Mine (with a portal in Placer Gulch), but the connection is at least 150 feet higher than land surface in the Sunnyside Basin.

Once an equilibrium water level is established in the flooded mine workings (and perhaps even earlier) some water is expected to move along natural fracture pathways from the flooded mine workings toward the Cement Creek Basin. The natural pre-mining ground-water flow directions (discussed in Section 3.4) are expected to be reestablished. The majority of the ground-water flow is expected to be toward the west and southwest as indicated on Figure 8. Most of the permeable fractures are oriented southwest, but the Brenneman vein also appears to be somewhat permeable and is oriented west-northwest. The estimated rate of ground-water flow through the flooded mine workings is discussed in Section 8.2 and the transit time from the mine workings to the surface is considered in Section 8.3.


Red Mountain No. 2 12,219
Red Mountain No. 1 12,592
Red Mountain No. 3 12,747
Mogul Mine 11,400
Mogul Spring 11,280
Area of Sunnyside Mine Stopes
Direction of Possible Ground-Water Flow in the Brenneman Vein
Cement Creek Basin
Anticipated General Direction of Ground-Water Flow
Sunnyside Basin
Terry Tunnel 11,560
Eureka Creek
Gladstone
American Tunnel Portal 10,617
Cement Creek
South Fork
Silver Ledge Mine
To Animas River
To Animas River
Note: Locations of stopes in Sunnyside Basin are generalized.
Scale: 1"=3000'
Sunnyside Gold Corporation
San Juan County, Colorado
Anticipated Principal Direction of Ground-Water Flow After Bulkhead Installation
DATE: 02/25/93
DESIGNED:
CHECKED:
APPROVED:
DRAWN: RAS
PROJ.: 187112251
SIMON HYDRO-SEARCH
Figure 8

5.0 ESTIMATION OF HYDRAULIC HEAD AND HYDRAULIC CONDUCTIVITY FROM FLOW TESTS

The average hydraulic conductivity of the fractured volcanic rocks near the 0700 and 1500 runarounds in the American Tunnel is estimated to be on the order of $5x10^{-5}$ cm/sec (0.15 feet/day). These conclusions are based on an analysis of flow tests described in detail in the remainder of this section. Rock in the vicinity of the flow tests may be somewhat more permeable than is typical for the deep rocks in the vicinity of the Sunnyside Mine.

Constant discharge flow tests were conducted on December 17 and 18, 1992, from two longholes (diamond drill holes) located in the American Tunnel. The purpose of these tests was to estimate the present hydraulic head over the American Tunnel and to estimate the average hydraulic conductivity of the fractured volcanic rocks in the vicinity of the tests. The analytical techniques applied to the test results can only produce rough averages over the entire length of open borehole.

5.1 Description of the Drill Holes Used for Flow Testing

In the Terry Tunnel (F-level) a diamond drill hole was drilled in late 1992 for the purpose of estimating hydraulic parameters. The hole was drilled east-northeast from the general vicinity of one of the bulkhead sites proposed by SGC. As expected, the hole did not encounter water and no flow testing was conducted.

In the American Tunnel three longholes (700, 702 and 704) were collared at the 1500 Runaround on the southeast rib and drilled to the southeast at different angles. The longholes were originally drilled for mineral exploration objectives, not for estimating hydraulic parameters. Hole 700 was drilled at an upward angle of ½ degree; hole 702 was drilled at an upward angle of 10 degrees; and hole 704 was drilled at a downward angle of 10 degrees. "Downhole" surveys were not conducted in any of these longholes. All three holes were grouted at the collar and fitted with shut-off valves and pressure gauges in preparation for the flow tests. Two longholes (781 and 778) were located at the 0700 Runaround. Hole 781 was drilled into the southeast rib at an upward angle of 17 degrees, but was not surveyed. Hole 778 was drilled into the northwest rib at a bearing to the north-northeast. Continuous downhole surveys show the hole started at an upward angle of 9 degrees and finished at an upward angle of 24 degrees.

5.2 Flow Test Methodology

The first flow test was conducted from hole 700 at a constant discharge of 135 gallons per minute (gpm). A Water Specialties Corporation model ML-04 flowmeter was used to measure discharge and Ashcroft 300 psi gauges were used to measure water pressures in the discharge line from hole 700 and at the collars of holes 702 and 704. Holes 781 and 778 at the 0700 Runaround were checked during the test; however, neither hole responded to the first test. The flow test was conducted for

four hours and five minutes (245 minutes). Recovery was monitored in holes 700 and 704 for 90 minutes after hole 700 was shut in.

The second flow test was conducted from hole 781 at a constant discharge of approximately 48.5 gpm. The test lasted four hours (240 minutes) and recovery was monitored for 90 minutes. The longholes at the 1500 Runaround were not monitored during the second test.

5.3 Measurement of Hydraulic Head

No water was encountered in the drill hole in the Terry Tunnel (F-level). However, circulation was lost into an open fracture at one point indicating that there is some fracture permeability. The lack of water in the presence of fracture permeability proves that the fractured rocks surrounding the Terry Tunnel (nominal elevation 11,562 feet msl) are not presently saturated. Unsaturated rocks were expected at F-level based on the apparent equilibrium water levels observed in 1959 - 1961 (Section 3.0).

Water flows from all drill holes in the vicinity of the 0700 and 1500 runarounds in the American Tunnel (nominal elevation 10,668). This indicates that the American Tunnel is below the water table. The permeability of the volcanic rocks is generally so low that water only enters the tunnel in a few permeable fractures.

Table 2. Hydraulic Head Measured in Boreholes in the American Tunnel

Hole Number	Length (feet)	Angle from Horizontal (degrees)	Estimated Elevation Change Along Hole (feet)	Static Head (psi)	Static Head Above American Tunnel Level (feet)
700	2022	+ 1/2	+ 18	132	304
702	1012	+ 10	+ 176	79	182
704		- 10	—	129	298
781	660	+ 17	+ 193	132	304

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The static hydraulic heads measured in the drill holes are given in Table 2. The measured hydraulic heads represent mix of heads over the length of the boreholes and it is not possible to precisely relate the hydraulic head to distance from the American Tunnel. However, it is clear that the hydraulic head in the vicinity of the tests is generally approximately 300 feet higher than the American Tunnel.

The area of the test is relatively highly fractured and serves to drain water from the fractured bedrock into the mine. Hence, the measured hydraulic heads do not represent the static equilibrium that would exist without the mine workings, but, rather, a cone of depression induced by the presence of the mine.

5.4 Estimate of Hydraulic Conductivity

Both log-log and semi-log plots of the rate of pressure change with time during the flow periods for holes 700, 702, and 704 (first test) and hole 781 (second test) are given in Appendix A. Semi-log recovery plots of pressure build-up versus t/t' (time since flow began divided by the time since flow was terminated) also are included. The drawdown plots for the first test do not provide for simple analysis by the Theis or Cooper-Jacob (1946) methods. This is probably due to turbulent flow within the small-diameter, uncased longhole (hole 700) and boundary effects along the highly transmissive fractures. Hole 700 drawdown data shows a more atypical plot than the drawdown data from holes 702 and 704.

However, the semi-log plots of the recovery data from both 700 and 704 produced straight lines. The calculated "transmissivities" from the recovery plots for 700 and 704 are 2,000 gallons per day per foot (gpd/ft) and 1,300 gpd/ft, respectively (Table 3). Due to the nature of the testing these calculated values should not be considered true transmissivities. Rather, the calculated value is a function of the average hydraulic conductivity and the length of the hole. The calculated hydraulic conductivities range from 0.1 to 0.2 ft/day. The calculated hydraulic conductivities are expected to be of the correct order of magnitude.

Both the semi-log drawdown and recovery plots for the second test (hole 781) produced straight lines. The calculated hydraulic conductivities are on the order of 0.2 ft/day.

The geometric mean of the calculated hydraulic conductivities is 0.15 ft/day. However, the rock in the vicinity of the flow tests exhibits more fracture permeability than is typical for the American Tunnel. Therefore, this calculated hydraulic conductivity is expected to be considerably higher than the general average for fractured rocks in the area.

Table 3. Hydraulic Conductivities Estimated from Flow Tests in the American Tunnel

Hole	Calculated "Transmissivity" Early Time gpd/ft	Calculated "Transmissivity" Late Time gpd/ft	Data Type	Length	Estimated Hydraulic Conductivity ft/day	Hydraulic Conductivity cm/sec
700	2,000	1,325	Recovery Test	2022	0.1 3/0.09	$4.6x10^{-5}$/ $3.2x10^{-5}$
704	1,300		Recovery Test	1012	0.17	$6.0x10^{-5}$
781	980		Drawdown Test	660	0.20	$7.0x10^{-5}$
781	930		Recovery Test	660	0.19	$6.6x10^{-5}$
Geometric Mean					0.15	$5.3x10^{-5}$

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6.0 RATE OF FLOODING OF MINE WORKINGS

The rate at which the underground workings will fill with water after installation of the proposed bulkheads depends upon the volume of mine workings, at the rate of inflow of water to the mine workings, and the porosity of the surrounding fractured volcanic rocks. Two methods of estimating the schedule of mine flooding predict that the water level will substantially reach equilibrium (86% of equilibrium) in a range of between one and ten years.

6.1 Estimate Using Volume of Workings and Constant Flow

SGC staff used detailed maps and sections of the underground workings of the Sunnyside Mine to calculate the volume of mine workings in increments of 100 vertical feet. Sections along stopes and tunnels were planimetered and compared to widths on plan views or to measured stope widths. The resulting mine volume data are summarized in Table 4. A more detailed volumetric analysis may be found in Appendix B.

One method of estimating the schedule at which the mine workings will fill with water is to assume that the volume of water entering the mine workings will remain constant until an equilibrium water level is reached. Table 4 shows the schedule of flooding using this method. The estimated time to flood the mine to the anticipated equilibrium water level of 11,500 feet msl using 930 gpm (the present flow rate at

Table 4. Volume of Sunnyside Workings by Level and Calculated Time to Flood Workings

Vein Section	Total Cum. cu.ft.	Total Cum. Gal.	Days 930 gpm	Days 1230 gpm
10700	1431680	10710462	8	6
10800	4235240	31679595	24	18
10900	7295720	54571906	41	31
11000	9369288	70082274	52	40
11100	10834208	81039876	61	46
11200	11950003	89386060	67	50
11300	14378852	107553813	80	61
11400	18289228	136803425	102	77
11500	26120289	195379762	146	110
11600	34284871	256450835	191	145
11700	45373477	339393608	253	192
11800	53433594	399683283	298	226
11900	59985360	448690493	335	253
12000	64385568	481604049	360	272
12100	67889040	507810019	379	287
12200	70358352	526280473	393	297

Note: Calculation assumes inflow rate is constant and surrounding rock has no porosity

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the proposed American Tunnel bulkhead site) is 146 days. Assuming a constant inflow rate of 1230 gpm (the American Tunnel flow rate plus slightly more than the historical average flow from the Terry Tunnel) yields 110 days. In actuality, the rate of inflow will decrease as the water level rises in the flooding workings. In a more conservative case, the time required to completely flood the mine workings would be slightly over two years if the average inflow rate is half of the present American Tunnel flow rate, and that the equilibrium water level is actually at the surface in Sunnyside Basin.

6.2 Estimate Using a Ground-Water Flow Model

The estimated schedules of the flooding of mine workings discussed in section 6.1 do not consider changes in inflow rate with time, nor porosity of the fractured volcanic rocks. To overcome these simplifications a numerical ground-water flow model was developed. The U.S. Geological Survey MODFLOW code was employed to create a simple model of the mine drainage via the American Tunnel.

The model employed a number of simplifying assumptions including

- initial hydraulic head prior to mine dewatering is constant at an elevation of 11,370 feet msl,
- hydraulic conductivity is constant at 0.15 ft/day (the geometric mean of the results of flow testing in the American Tunnel),
- the fractured volcanic rocks are only permeable down to an elevation of 9668 feet msl (1000 feet below the American Tunnel Level),
- the storativity is constant at 0.01,
- there is no recharge from above or below, and
- all inflow to the mine is from constant head boundaries at a distance of over four miles from the mine workings.

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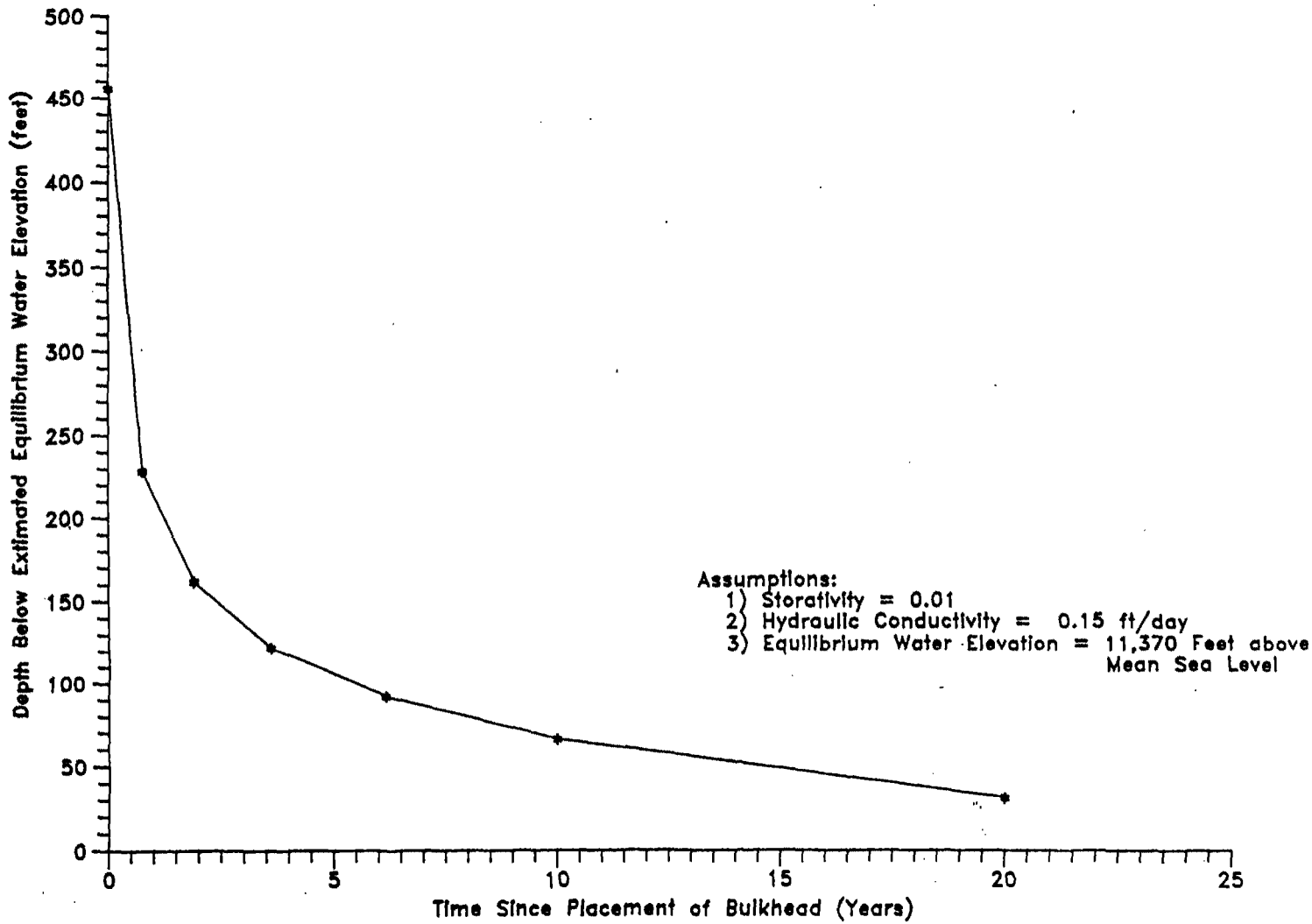
Although the initial hydraulic head employed in the model is somewhat lower than the expected equilibrium water level, the estimated drawdown and recovery rates would not be significantly affected by the difference. In spite of the simplifying assumptions, the model is useful for obtaining a rough approximation of the flooding schedule.

The American Tunnel began draining the Sunnyside Mine in early 1961 (approximately 33 years prior to estimated bulkhead construction). During modeling the mine was allowed to dewater the surrounding fractured rocks for a modeled time interval of 33 years via a drain at the American Tunnel Level. The drain in the model was calibrated so that the average discharge from the drain was 899 gpm (compared to a present discharge of approximately 930 gpm). The model predicted head after 33 years of draining also corresponds well to the observed heads near the 0700 and 1500 runarounds (Section 5.3). After the 33 years of dewatering the drain was "plugged" to simulate bulkhead construction. The model-estimated rate of mine flooding is shown on Figure 9. The mine is modeled as being 86% filled with water in 10 years.

Reasonable estimates of hydraulic parameters were employed in the model. If the actual average porosity is greater than the modeled value (0.01) the mine will refill somewhat more slowly than modeled. If the actual average hydraulic conductivity is less than the modeled hydraulic conductivity (0.15 ft/day) then the mine will also refill somewhat more slowly than modeled. These effects should be more than offset by



Sunnyside Gold Corporation San Juan County, Colorado	DATE: 03/08/93
	DESIGNED: RGB
Schedule of Mine Flooding Based on MODFLOW Model	CHECKED:
	APPROVED:
	DRAWN: RAS
	PROJ.: 187112251
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the fact that there will be some recharge from the surface which will probably be roughly equivalent to the annual average discharge from the Terry Tunnel. In 1992 the average Terry Tunnel discharge was approximately 215 gpm, but it is expected to be less than 100 gpm after completion of surface water diversions in the Sunnyside Basin.

7.0 RATE OF LEAKAGE AROUND BULKHEADS

The rate of leakage through the bedrock in the immediate vicinity of each proposed bulkhead is expected to be less than 25 gallons per minute. Support for this estimate is detailed in the remainder of this section. The bulkhead design by Dr. John Abel (see "Bulkhead Design for the Sunnyside Mine: Sunnyside Gold Corp., An Echo Bay Company", 1993) is intended to minimize the amount of leakage through the bulkhead itself, and at the contact between the bulkhead and the bedrock. The anticipated overall rate of ground-water flow from the flooded mine workings to Cement Creek is discussed in Section 8.2.

7.1 Equilibrium Water Level Behind the Bulkheads

The water level behind the proposed bulkheads is expected to rise until the rate of outflow from the flooded mine workings is equal to the rate of inflow from the ground water system and openings in Sunnyside Basin. The outflow will be via natural (fracture) pathways because all possible man-made pathways will be blocked by bulkheads all the way up to the level of the surface in Sunnyside Basin.

The equilibrium water level in the flooded mine workings is anticipated to be just below F level (approximately 11,500 feet msl). This is based on historical observations of water levels in the Sunnyside Mine after 20 years of inactivity (Simon Hydro-Search, 1992, pp. 18-19).

Direct surface-water inflow to the mine was less during the aforementioned observations (1959-1961) than during recent years. The increase in surface-water inflow in recent years has resulted from the opening of the Lake Emma Hole and auto-stoping of other mine workings to the surface (Simon Hydro-Search, 1992, pp. 35-36). However, ongoing reclamation work in Sunnyside Basin has filled the Lake Emma Hole, and blocked or diverted many of the other sources of surface water.

If the amount of surface water inflow continues to be greater than during the 1959-1961 observations, then the equilibrium water level may be correspondingly higher. Therefore, leakage analyses contained in later sections of this report contain estimates based on both expected equilibrium water lever (near F level), and a most conservative case (surface level in Sunnyside Basin).

7.2 Permeability at Proposed Bulkhead Sites

Cores were taken of the wall rock at each of the proposed bulkhead sites (American Tunnel, Terry Tunnel, F-Level Brenneman and B-Level Brenneman). These cores were submitted to Petroleum Testing Service, Inc. of California for laboratory measurement of permeability to water. Permeability was measured using EPA Method 9100 with a 250 psi net confining stress at 74°F.

Hydraulic conductivities ranged from 10^{-8} to 10^{-10} cm/sec for unfractured core, to 10^{-6} cm/sec for core showing fractures. Results are summarized in Table 5. The

Table 5. Permeabilities Based on Laboratory Testing of Rock Cores		
Sample I.D.	Water Permeability Test 250 psi Net Confining Stress at 74°F	
	Effective Permeability milldarcy	Hydraulic Conductivity cm/s
B-Level Nth Rib	0.002	$2.08x10^{-8}$
B-Level Sth Rib	0.002	$2.08x10^{-8}$
Brenneman Back	0.001	$5.31x10^{-10}$
Brenneman Nth Rib	0.006	$6.25x10^{-8}$
Brenneman Sth Rib	0.001	$6.35x10^{-10}$
Terry Tunnel Back **	4.27	$4.44x10^{-6}$
Terry Tunnel Nth Rib	0.002	$2.08x10^{-8}$
Terry Tunnel Sth Rib	0.002	$2.08x10^{-8}$
American Tunnel Back	0.013	$1.35x10^{-6}$
American Tunnel Nth Rib	0.001	$1.04x10^{-8}$
American Tunnel Sth Rib **	9.27	$9.66x10^{-6}$

** Fractured sample
* EPA Method 9100

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extremely low hydraulic conductivities were expected in the unfractured volcanic rocks (Freeze and Cherry, 1979, p.29).

The fractured core is thought to be the result of rock damage caused by blasting during construction of the underground workings. Such blast damage is limited to the immediate vicinity of the mine workings, typically extending no more than 5 feet (Worsey, 1985; Worsey, 1986; and Siskind and Fumati, 1974). Hence, a damaged rim a few feet thick around the tunnels is expected to have an artificially induced permeability of 10^{-6} cm/sec.

Flow testing of boreholes in the American Tunnel resulted in an overall hydraulic conductivity of $5x10^{-5}$ cm/sec when averaged from boreholes oriented perpendicular to the general orientation of the fracture system (see Section 4.0). The hydraulic conductivity of $5x10^{-5}$ cm/sec results from a relative few, widely-spaced fractures. The proposed bulkhead sites were selected in areas where no major fractures were observed. Hence, for the purpose of calculating leakage in the immediate vicinity of the proposed bulkheads a value of $5x10^{-5}$ cm/sec is probably too high.

7.3 Leakage in the Immediate Vicinity of the Bulkheads

Darcy's equation was used to estimate the rate of leakage through the fractured volcanics in the immediate vicinity of the proposed bulkheads. Darcy's equation is:

$Q = KIA$ where:

Q = discharge (i.e. leakage)
K = hydraulic conductivity
I = gradient, and
A = the cross-sectional area of the "aquifer" through which water flows.

A spreadsheet (Table 6) was developed in order to allow a range values of hydraulic conductivity, gradient, and area. The expected values correspond to a hydraulic conductivity of 10^{-6} cm/sec, a hydraulic head near F-Level, and a blast damage zone out to 3 feet from the mine walls. The leakage through the fractured volcanics is expected to be less than 0.1 gallon per minute (Case B on Table 6). Conservative values correspond to a hydraulic conductivity of 5×10^{-5} cm/sec and a hydraulic head at the level of the land surface in Sunnyside Basin. The leakage via the fractured volcanics in the conservative case is still less than 25 gallons per minute at any given bulkhead (Case I on Table 6).

Table 6. Sunnyside Mine Ground–Water Flow Around Bulkhead Calculation Sheet

Performed by Bob Butler 12/24/92 revised 12/28/92

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE A	Brenneman B	1.00E−06	2.83E−03	12122	3	42.67	100	256	156	0.10	141
	Brenneman F	1.00E−06	2.83E−03	11562	8	86.00	100	256	156	0.20	284
	Terry F	1.00E−06	2.83E−03	11562	8	86.00	144	324	180	0.23	328
	American	1.00E−06	2.83E−03	10668	25	63.28	169	361	192	0.18	258

Note: Assumes Static Head Elevation of 12250 (Lake Emma) and 3 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE B	Brenneman B	1.00E−06	2.83E−03	12122	3	*	100	256	156	*	*
	Brenneman F	1.00E−06	2.83E−03	11562	8	3.75	100	256	156	0.01	12
	Terry F	1.00E−06	2.83E−03	11562	8	3.75	144	324	180	0.01	14
	American	1.00E−06	2.83E−03	10668	25	36.96	169	361	192	0.10	150

Note: Assumes Static Head Elevation of 11592 ("F" Level plus 30 feet) and 3 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE C	Brenneman B	1.00E−10	2.83E−07	12122	3	42.67	100	256	156	0.00001	0.01
	Brenneman F	1.00E−10	2.83E−07	11562	8	86.00	100	256	156	0.00002	0.03
	Terry F	1.00E−10	2.83E−07	11562	8	86.00	144	324	180	0.00002	0.03
	American	1.00E−10	2.83E−07	10668	25	63.28	169	361	192	0.00002	0.03

Note: Assumes Static Head Elevation of 12250 (Lake Emma) and 3 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE D	Brenneman B	1.00E−10	2.83E−07	12122	3	*	100	256	156	*	*
	Brenneman F	1.00E−10	2.83E−07	11562	8	3.75	100	256	156	8.61E−07	0.001
	Terry F	1.00E−10	2.83E−07	11562	8	3.75	144	324	180	9.94E−07	0.001
	American	1.00E−10	2.83E−07	10668	25	36.96	169	361	192	1.04E−05	0.015

Note: Assumes Static Head Elevation of 11592 ("F" Level plus 30 feet) and 3 foot fracture distance from each side of the plug.

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Table 6. Sunnyside Mine Ground–Water Flow Around Bulkhead Calculation Sheet

Performed by Bob Butler 12/24/92 revised 12/28/92

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE E	Brenneman B	1.00E−06	2.83E−03	12122	3	42.67	100	400	300	0.19	271
	Brenneman F	1.00E−06	2.83E−03	11562	8	86.00	100	400	300	0.38	547
	Terry F	1.00E−06	2.83E−03	11562	8	86.00	144	484	340	0.43	620
	American	1.00E−06	2.83E−03	10668	25	63.28	169	529	360	0.34	483

Note: Assumes Static Head Elevation of 12250 (Lake Emma) and 5 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE F	Brenneman B	1.00E−06	2.83E−03	12122	3	*	100	400	300	*	*
	Brenneman F	1.00E−06	2.83E−03	11562	8	3.75	100	400	300	0.02	24
	Terry F	1.00E−06	2.83E−03	11562	8	3.75	144	484	340	0.02	27
	American	1.00E−06	2.83E−03	10668	25	36.96	169	529	360	0.20	282

Note: Assumes Static Head Elevation of 11592 ("F" Level plus 30 feet) and 5 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE G	Brenneman B	1.00E−10	2.83E−07	12122	3	42.67	100	400	300	0.00002	0.03
	Brenneman F	1.00E−10	2.83E−07	11562	8	86.00	100	400	300	0.00004	0.05
	Terry F	1.00E−10	2.83E−07	11562	8	86.00	144	484	340	0.00004	0.06
	American	1.00E−10	2.83E−07	10668	25	63.28	169	529	360	0.00003	0.05

Note: Assumes Static Head Elevation of 12250 (Lake Emma) and 5 foot fracture distance from each side of the plug.

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE H	Brenneman B	1.00E−10	2.83E−07	12122	3	*	100	400	300	*	*
	Brenneman F	1.00E−10	2.83E−07	11562	8	3.75	100	400	300	1.66E−06	0.002
	Terry F	1.00E−10	2.83E−07	11562	8	3.75	144	484	340	1.88E−06	0.003
	American	1.00E−10	2.83E−07	10668	25	36.96	169	529	360	1.96E−05	0.028

Note: Assumes Static Head Elevation of 11592 ("F" Level plus 30 feet) and 5 foot fracture distance from each side of the plug.

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Table 6. Sunnyside Mine Ground–Water Flow Around Bulkhead Calculation Sheet

Performed by Bob Butler 12/24/92 revised 12/28/92

	Adit (name)	Permeability (cm/sec)	Permeability (ft/day)	Adit Elevation (feet)	Length of Plug (feet)	Hydraulic Gradient (feet/foot)	Cross Sectional Plug Area (feet²)	Cross Sectional Flow & Plug Area (feet²)	Cross Sectional Flow Area (feet²)	Calculated Flow (gpm)	Calculated Flow (gpd)
CASE I	Brenneman B	5.25E−05	1.49E−01	12122	3	42.67	100	400	300	9.9	14,249
	Brenneman F	5.25E−05	1.49E−01	11562	8	86.00	100	400	300	19.9	28,722
	Terry F	5.25E−05	1.49E−01	11562	8	86.00	144	484	340	22.6	32,551
	American	5.25E−05	1.49E−01	10668	25	63.28	169	529	360	17.6	25,360

Note: Assumes Static Head Elevation of 12250 (Lake Emma) and 5 foot fracture distance from each side of the plug.

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8.0 MOVEMENT OF WATER FROM FLOODED WORKINGS TO THE SURFACE

An equilibrium water level is anticipated to occur in the flooding mine workings in less than 10 years (see Section 6). Under equilibrium conditions the rate of inflow to the flooded workings will equal the rate of outflow. The ground-water flow which passes through flooded mine workings is expected to be approximately 70 gpm, but could be as great as 200 gpm. This ground water is expected to discharge over a long stretch of Cement Creek. The travel time from the flooded workings to Cement Creek is estimated at approximately 150 years. Under the very unlikely scenario that the equilibrium water level in the flooded workings is at 12,250 feet msl, some of the water could reach Cement Creek (via the Mogul Mine) in as little as 4 months.

8.1 Nature of the Discharge from Flooded Mine Workings

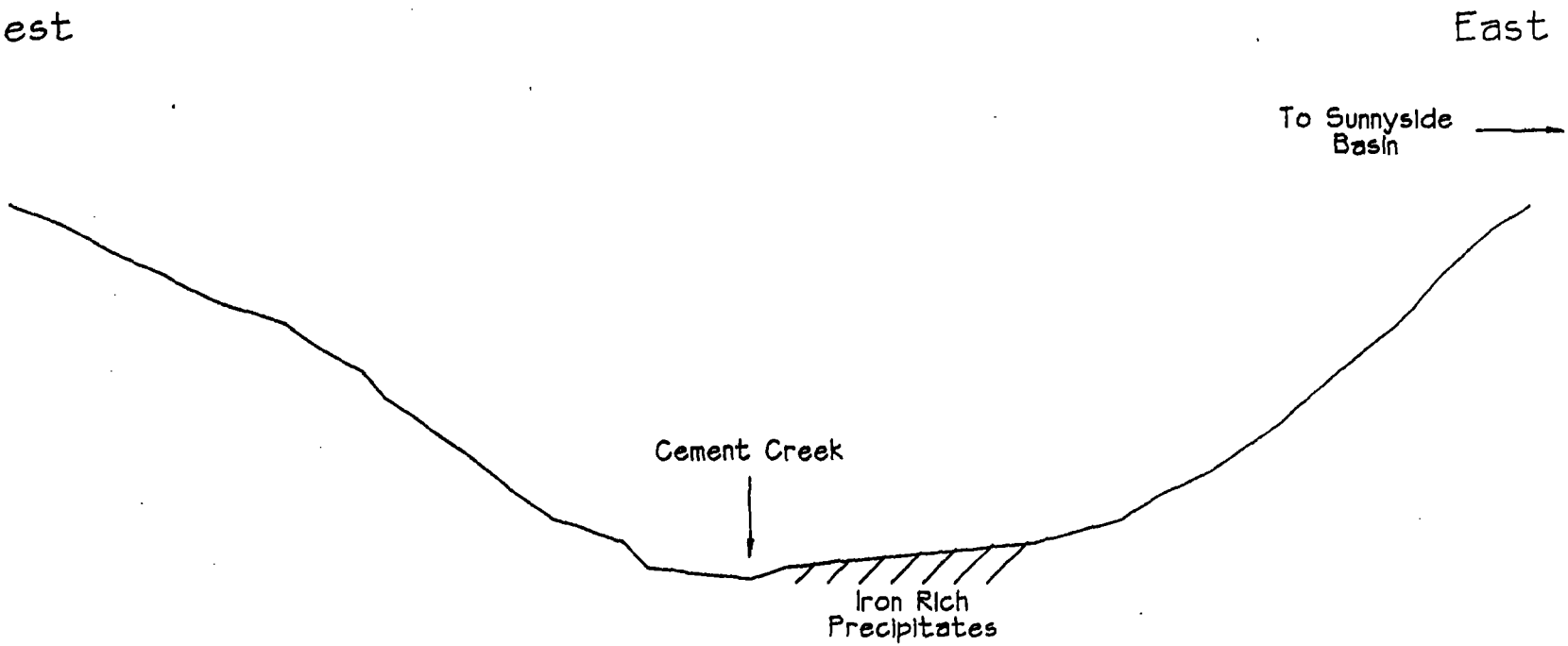
Water leaving the flooded mine workings is expected to move primarily along natural flow paths through fractures in the volcanic rocks until it discharges along Cement Creek. The ground water is expected to move toward Cement Creek because the natural fracture system has enhanced permeability in that direction and because the hydraulic gradient between Sunnyside Basin and Cement Creek is the same as, or greater than, in other directions (Section 3.4).

Based upon the preferred fracture orientation (Section 3.2) the ground water would be expected to move generally southwest from Sunnyside Basin toward Cement

Creek. However, some ground water may also follow pathways along, or parallel to, the Ross Basin fault (Brenneman vein) and Bonita fault. These pathways would allow for ground-water discharge along a stretch of Cement Creek between the Mogul Mine (on the north) and the Silver Ledge Mine (on the south).

A cross section across Cement Creek between the Mogul Mine and Gladstone (near the Red and Bonita Mine) is clearly asymmetrical rather than a classic "V" shape (Figure 10). This asymmetry correlates with the distribution of present and former iron "bogs" and is thought to result from springs depositing mineral precipitates. The build up of precipitates would have gradually forced Cement Creek toward the west. Hence, based upon the local geomorphology ground-water appears to have discharged preferentially along the part of Cement Creek between the Mogul Mine and Gladstone. Furthermore, the discharge appears to have been diffuse rather than concentrated at one spring.

If the equilibrium water level in the mine is significantly higher than expected, some portion of the outflow from the flooded mine workings may discharge to Eureka Gulch. The possible discharge to Eureka Gulch would occur via the more generalized fracture permeability which exists at shallow depths where overburden pressure is relatively less (Section 3.2).



Profile digitized from U.S. Geological Survey "Ironton" 7 1/2 minute topographic map.

Scale: 1"=300'
0 150' 300'

N

Sunnyside Gold Corporation San Juan County, Colorado	DATE: 02/11/93 DESIGNED: CHECKED: APPROVED: DRAWN: RJJ PROJ.: 201872025
Topographic Profile Across Cement Creek	
SIMON	Figure 10

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At the expected equilibrium water level, the American Tunnel will be the only man-made pathway out of the mine, and it will be blocked. In case the equilibrium water level is higher than expected, all other man-made pathways out of the Sunnyside Mine will also be blocked with bulkheads (at the Terry Tunnel, F-Level Brenneman, and B-Level Brenneman).

8.2 Estimated Rate of Flow through Flooded Mine Workings

The present rate of discharge from the American Tunnel is rather constant at approximately 1600 gpm. Of this, approximately 930 gpm originates upstream of the proposed bulkhead site near the underground SGC property line. The flow from the American Tunnel is almost all ground water rather than surface water inflow. The flow rates are stable and appear to represent an equilibrium condition.

As discussed in Section 3.4 the pre-mining ground-water movement was from Sunnyside Basin toward Cement Creek. The water entering the American Tunnel upstream of the bulkhead site has merely been captured on its way to Cement Creek and so that its transit time is reduced. The capture zone for water entering the mine workings extends well beyond the mine workings themselves. Therefore, the ground water which will pass through the Sunnyside Mine workings after an equilibrium water level is reached will be far less than 930 gpm.

Darcy's equation can be used to estimate a likely overall rate of ground-water flow expected to pass through the flooded mine workings. Darcy's equation is:

$$Q = KIA$$ where:

Q = discharge
K = hydraulic conductivity
I = gradient, and
A = the cross-sectional area of the "aquifer" through which water flows.

Based on flow tests in the American Tunnel (Section 5.4), the hydraulic conductivity in unusually fractured areas is estimated at 0.15 feet/day. However, typical hydraulic conductivity is expected to be more than an order of magnitude less.

Darcy's equation was applied to four scenarios in order to obtain a reasonable range of values for the ground-water flow expected to pass through the flooded mine workings (Table 7). Case 1 is considered the most likely, with an equilibrium water level in the mine at F level and a southwest flow direction. Case 1 uses the maximum width of stoped mine workings of 4560 feet. The resulting estimated rate of ground-water flow through the flooded mine workings is approximately 70 gpm. Case 2 is similar to Case 1 except it assumes the absolute maximum possible equilibrium water level of 12,250 feet (land surface in Sunnyside Basin) and results in an estimated flow of 200 gpm. The flow in cases 1 and 2 would be expected to discharge over a long stretch of Cement Creek as discussed in Section 8.1.

Table 7. Estimated Rates of Ground-Water Flow Expected to Pass Through Mine Workings to Cement Creek								
	Equilibrium Water Level in Mine (Feet msl)	Elevation of Discharge Zone (Feet msl)	Gradient	Saturated Thickness[7] (Feet)	Width of Flow Zone (Feet)	Area[8] (Ft^2)	Hydraulic Conductivity (Ft/day)	Discharge (GPM)[11] (rounded)
Case 1	11,562[1]	10,500[3]	.105[5]	894	4560[9]	$4x10^6$	0.03	70
Case 2	12,250[2]	10,500[3]	.18[5]	1582	4560[9]	$7x10^6$	0.03	200
Case 3	11,562[1]	11,400[4]	.06[5]	162	500[10]	$8x10^4$	0.15	4
Case 4	12,250[2]	11,400[4]	.32[5]	450	500[10]	$2x10^5$	0.15	160[13]
		11,850[14]	.67[12]	400	500[10]	$2x10^5$	0.15	

NOTES:

(1) Elevation of F-level (anticipated equilibrium water level in flooded mine workings).

(2) Elevation of land surface in Sunnyside Basin (maximum possible equilibrium water level).

(3) Elevation of Cement Creek near the portal of the American Tunnel. Expected elevation of ground-water discharge would range from 10,500 to 11,400. Hence, the calculation uses the lowest value for elevation and will result in an overestimate of discharge.

(4) Elevation of the Mogul Mine main level (which intersects the Brenneman vein).

(5) Calculated using the distance between the Sunnyside Basin and the American Tunnel portal (9,500 feet).

(6) Uses the scaled distance of 2,640 feet between the nearest stopes in the Sunnyside and Mogul Mines at an elevation of 11,400 feet msl.

(7) Equilibrium Water Level minus Elevation of Discharge Zone. This probably represents a maximum effective thickness and is expected to result in an overestimate of flow through the flooded workings.

(8) Saturated Thickness multiplied by Width of Flow Zone.

(9) Maximum width of flooded stoped workings in the Sunnyside Mine.

(10) Assumed width of highly fractured zone associated with the Brenneman vein. This is probably an overestimate and is expected to result in an overestimate of discharge via the Brenneman vein.

(11) Discharge calculated as Gradient times Area times Hydraulic Conductivity. As discussed in previous footnotes, these estimates may be somewhat high due to conservative assumptions.

(12) Uses the scaled distance of 600 feet between the nearest stopes in the Sunnyside and Mogul Mines at an elevation of 11,850 feet msl.

(13) This number results from adding the flow via the two paths. One path drains at the Mogul Mine main level. The other path drains at the Mogul #3 level.

(14) Elevation of the Mogul #3 level (which intersects the Brenneman vein).

Cases 3 and 4 assume ground water preferentially moving along the Brenneman vein and use the high hydraulic conductivity found in unusually fractured areas. Since the flow from the Brenneman vein is approximately equal to the flow in the area of the American Tunnel flow tests, it is reasonable to assume that the hydraulic conductivities are also similar. The width of enhanced fracture permeability is assumed to be 500 feet for the calculation, but it is probably less. If ground water does move along the Brenneman vein it will encounter the Mogul Mine workings at a distance of 2640 feet at an elevation of 11,400 feet. Case 3 assumes the expected equilibrium water level at F level and results in an estimated flow of 4 gpm. Case 4 assumes the absolute maximum possible equilibrium water level of 12,250 feet and results in an estimated flow of 160 gpm. The flow in cases 3 and 4 would discharge from the portal of the Mogul Mine.

When considering possible flow along the Brenneman vein, it should be emphasized that no flow is expected to take this route unless the equilibrium water level in the flooded mine workings exceeds 11,400 feet msl (the elevation of the Mogul Mine main level). At an equilibrium water level above 11,400 feet, ground water could begin to move via fracture permeability toward the Mogul Mine. Although a tunnel connection between the Sunnyside and Mogul Mines exists at an elevation of 11,904 feet msl, the actual tunnel connection is not expected to serve as a significant conduit for water movement. At the proposed bulkhead sites at both the F-level Brenneman and the B-level Brenneman, the bulkheads would actually consist of a pair of

bulkheads at each site. Each member of each pair of bulkheads would be constructed to the specifications recommended by Abel (1993) for a single bulkhead. The twinned bulkheads are proposed to be separated by a distance of more than 100 feet. The purpose of twinning the bulkheads is to reduce the chances of a random permeable fracture set in the rock bypassing a single bulkhead.

8.3 Transit Time for Flow from Mine Workings to the Surface

The time required for ground water to move from the flooded mine workings to Cement Creek can be roughly estimated with a form of Darcy's equation:

$$V = \frac{KI}{n}$$ Where:

V = velocity,
K = hydraulic conductivity,
I = gradient, and
n = effective porosity.

Assuming flow is to the southwest (as in cases 1 and 2 in Section 8.2), possible gradients range from 0.1 assuming a hydraulic head in the Sunnyside Basin to be just below F-Level (the most likely case), to a maximum of 0.18 (assuming a head in the Sunnyside Basin to be at land surface). Hydraulic conductivity in highly fractured areas is on the order of $5x10^{-5}$ cm/sec (0.15 ft/day) based on flow testing in the American Tunnel. However, this hydraulic conductivity is expected to be higher than average considering that the degree of fracturing is somewhat greater than normal in the vicinity of the flow testing. Average hydraulic conductivity is expected to be far

less than 0.15 feet/day and is assumed to be 0.03 feet/day for the most likely case. Porosity for fractured crystalline rock ranges up to 10% (Driscoll, 1986, p.67). Considering the high flow rates measured during testing, the porosity is unlikely to be less than 1 percent.

The first part of Table 8 lists the probable minimum, most likely, and probable maximum velocities and transit times of ground water between the flooded mine workings and diffuse discharge along Cement Creek. The second part of Table 8 lists the most likely and probably maximum velocities and transit times of ground water which might follow the Brenneman vein and intersect the idle workings of the Mogul Mine. If the equilibrium water level is approximately at F level (as expected) then the majority of the water passing through the flooded workings (estimated at 70 gpm) is expected to take over 150 years to reach Cement Creek, but a lesser amount (estimated at 4 gpm) may move via the Brenneman vein and have a transit time of approximately 16 years. In the unlikely event that the maximum possible equilibrium water level is reached, the estimated transit times would be reduced to about 10 and 1.5 years, respectively.

Table 8. Velocity and Travel Time for Ground-Water Flow Between Mine Workings and Cement Creek					
	Gradient	Hydraulic Conductivity Ft/Day	Porosity	Velocity Ft/Day	Time in Years
Assuming Southwest Flow and Diffuse Discharge Along Cement Creek					
Slow Case	.10[1]	0.003	.05	.006	4300
Most Likely Case	.105[1]	0.03	.02	.01	160
Fast Case	.18[2]	0.15	.01	2.7	9.6
Assuming Flow Along Brenneman Vein and Discharge Via Mogul Mine					
Most Likely Case	.06[1]	0.15	0.02	0.45	16
Fast Case	.67[2]	0.15	0.02	5.0	0.32

(1) Assumes the expected equilibrium water level at F-level

(2) Assumes the unlikely equilibrium water level at land surface in the Sunnyside Basin.

9.0 WATER CHEMISTRY AFTER INSTALLATION OF PROPOSED BULKHEADS

9.1 Introduction and Methodology

This section summarizes the results of numerical modeling of the geochemical questions associated with the proposed system of bulkheads: estimating the approximate chemistry of the impounded water, identifying what, if any, reactions may occur as impounded water moves either through the country rock around the bulkheads or as it moves through the natural fracture system back to the ground surface, predicting the character of the discharging water once it equilibrates to the atmosphere and precipitates any oversaturated minerals, and, finally, estimating the impact of the discharged water on the overall chemistry of Cement Creek. Numerical geochemical modeling is the computer-based simulation of the complex systems of rock-water interactions. It permits the simultaneous consideration of numerous chemical equilibria states and reactions among solid, aqueous and gaseous species. Geochemical modeling is valued as a check on conceptual models because it permits 1) examination of a total chemical system, as well as critical subsets of that system, 2) protection against oversights that can occur when complex systems are oversimplified, and 3) rapid investigation of modified or alternative expressions of the conceptual model.

The model used was MINTEQA2, versions 3.0 and 3.11. This is a metal speciation program developed by Battelle Northwest Laboratories and distributed by the United

States Environmental Protection Agency through the Center for Exposure Assessment Modeling, Athens, Georgia. The program was developed to model adsorptive retardation and quasi-equilibrium speciation of most metals of environmental concern and permits independent assignment of oxidation state to each of 25 redox pairs among metals. For this project, the adsorptive routines were not used, and the model was run as a full equilibrium model. The program is described in the EPA document "MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems: Version 3.0 User's Manual" (Allison, et al., 1991).

The objectives of the modeling were:

- Model the chemistry of waters associated with the proposed American Tunnel bulkhead system
  - Establish in-situ water characteristics (reference water) and compare to current mine drainage;
  - Project chemistry of water impounded behind deepest bulkhead of the American Tunnel; and
  - Identify reactions likely to occur along flow paths.
- Model the chemistry of water associated with the proposed Terry Tunnel bulkhead system
  - Model a reference water for the shallow mine levels;
  - Project chemistry of water impounded behind bulkhead in the Terry Tunnel; and
  - Identify reactions likely to occur along flow paths.
- Model surface discharge of reference waters and mixed waters; and
- Investigate the impact of discharge waters on surface water chemistry.

Details of the modeling are included in Appendix C of this report. This section contains a summary of the results of the modeling.

9.2 Impounded Water at the American Tunnel Level

Water that will be impounded behind the American Tunnel is conceptualized as ground water from the fractured volcanic rocks that make up the country rock. Whole water analyses of this water were collected from drill holes extending several hundreds of feet back from the tunnel and are the best estimate of the bulk water chemistry. The chemical analyses of these drill hole waters are shown in Table 9.

Integrating the data from these and other whole water analyses from the deeper portions of the American Tunnel, metals-only analyses, petrographic data (Appendix D and Casadevall and Ohmoto) and local and regional geology produced a modeled reference water for the American Tunnel. This reference water is descriptive of both the in-situ ground water of the country rock and of the water that will be impounded behind the American Tunnel bulkhead. The composition of this water is shown in Table 10. The reference water is a calcium sulfate water with significant bicarbonate concentrations. Based on being in equilibrium with both calcite and pyrite the modeled water is strongly reduced (pE = -2.5) and is slightly basic of neutral (pH = 7.2).

MINTEQA2 shows the reference water to be at saturation or equilibrium with both the rock-forming minerals of the country rock and with the principal ore and vein minerals that would be associated with the migration paths to the surface. There should be no significant reaction between the American Tunnel reference water and minerals

Table 9. Water analyses from the American and Terry Tunnels

This table gives the results of laboratory analyses.

Location	Date	Source	Flow MGD	Field pH	Field Conduct	Field Temp deg-C	Lab pH	Lab Conduct	TDS	TSS
AMERICAN TUNNEL										
DH-781	10/07/91	pipe		7.32	1140	13	7.06	1540	1360	6
DH-778	10/07/91	pipe		7.54	1200	12.8	6.39	1610	1420	63
DH-778	01/04/93	pipe					7.50	1810	1600	4
TERRY TUNNEL										
Upstream of Lime Treatment	06/11/91	ditch	1.30	5.60		10.0	5.33	528	359	92
Upstream of Lime Treatment	06/17/91	ditch	1.80	4.40		9.9	4.2	587	426	166
Upstream of Lime Treatment	07/11/91	ditch	0.33	4.10			3.32	933	726	54

Location	Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Sr	Al	K	Si
AMERICAN TUNNEL											
DH-781	905	102.0	1.33	<0.1	390	4.6	6.2	4.99	0.8	<.1	
DH-778	925	153.0	2.87	<0.1	414	3.0	4.0	3.78	0.6	<.1	
DH-778	1100	104.0	0.92	1.30	400	6.3	44.0	13.70	0.1	0.40	>3.7
TERRY TUNNEL											
Upstream of Lime Treatment	264	3.05	2.37	1.42	55.7	1.5	33.9	0.56	0.9	1.14	
Upstream of Lime Treatment	300	0.00	3.38	5.31	117.0	2.2	0.1	0.61	1.5	1.73	
Upstream of Lime Treatment	544	0.00	5.56	0.30	160.0	1.7	19.0	0.98	3.2	1.20	

Location	Metals Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)	Copper (Diss)	Copper (Total)
AMERICAN TUNNEL												
DH-781	<.05		1.17		0.05		0.02		<.002		<.01	
DH-778	1.59		6.91		4.25		<.02		0.030		<.01	
DH-778	<.05	0.13	1.21	1.25	<.01	<.01	<.005	<.005	<.002	<.002	0.01	0.01
TERRY TUNNEL												
Upstream of Lime Treatment	0.1		29.1		20.1	20.41	0.06	1.00	0.09	0.06	1.43	1.83
Upstream of Lime Treatment	0.7		37.4		25.3		0.06		0.02		2.77	
Upstream of Lime Treatment	4.1	13.2	76.8	77.8	47.3	47.6	0.88	1.05	0.19	0.19	5.05	5.11

Location	Metals (con't.) Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
AMERICAN TUNNEL								
DH-781	<.001		<.005	<.01	<.02	<.05	<.005	<.01
DH-778	<.001		<.005	<.01	<.02	0.060	<.005	<.01
DH-778	<.001	<.001	<.005		<.02	0.005	<.005	0.030
TERRY TUNNEL								
Upstream of Lime Treatment	<.0002	<.0002	<.002	<.05	<.02	<.05	<.002	<.01
Upstream of Lime Treatment	<.0002		<.002	<.01	<.02	<.05	<.002	<.01
Upstream of Lime Treatment	<.0002	<.0002	0.008	0.08	<.02	<.05	<.002	<.01

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Table 10. Reference waters
(THIS TABLE GIVES THE RESULTS OF MINTEQA2 MODELING)

AMERICAN TUNNEL		TERRY TUNNEL	
Analyte	*Concentration mg/L*	*Analyte*	*Concentration mg/L*
Sulfate	925	Sulfate	544
Bicarbonate	150	Bicarbonate	6.41
Chloride	0.05	Chloride	0.3
Fluoride	2.97	Fluoride	5.56
Phosphate	0.007		
		Calcium	160
Calcium	414	Magnesium	19
Magnesium	4.03	Sodium	1.7
Sodium	2.99	Aluminum	3.2
Aluminum	0.6	Potassium	1.2
Potassium	0.05	Silica	5.3
Silica	5.93		
		Iron	13.24
Iron	2.75	Manganese	77.78
Manganese	8.08	Copper	5.11
Zinc	5	Zinc	47.6
Strontium	3.78	Strontium	0.98
Cadmium	0.04	Cadmium	0.19
Lead	0.025	Lead	1.05
pH	7.18	pH	7.01
pE	−2.46	pE	−1.50

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along either migration around the bulkhead or along the fracture network back to the surface and therefore no significant changes in water chemistry.

9.3 Impounded Water at the Terry Tunnel Level

Drainage from the Terry Tunnel that will be diverted into the mine workings and potentially impounded by a bulkhead to be placed in the Terry Tunnel is a composite flow of water drainage into the mine workings through surface openings and unsaturated flow through the vadose zone. The only available samples of the Terry Tunnel water are mixes of these sources of water. Table 9 shows the available whole water analyses of Terry Tunnel mine drainage.

Integrating the data from the whole water analyses with analyses of metals-only, petrographic data and regional and local geologic information permitted a Terry Tunnel reference water to be modeled. This reference water is descriptive of the water that will likely be impounded by a Terry Tunnel bulkhead and is believed to be representative of, and dominantly controlled by, the flow through natural fractures and unsaturated flow through the vadose zone. The composition of the Terry Tunnel reference is shown in Table 10. This reference water is also a calcium sulfate water but with very reduced bicarbonate concentrations. Both in-situ and when impounded, it is believed to be neutral (pH estimated at 7.0) and reduced (but not as reduced as the American Tunnel water). Although the total dissolved solids concentration is less than that of the American Tunnel reference water, the individual and total metals load

is substantially higher. Copper is present in the Terry Tunnel reference water, whereas it was not present in the ground water at the American Tunnel level in consistently detectable concentrations.

MINTEQA2 calculations show the Terry Tunnel reference water to be at equilibrium or oversaturated with most of the major rock-forming minerals that are present in the country rock at that level. The impounded water is expected to be somewhat unsaturated with respect to calcite. The overall reaction with country rock should be minimal and will probably decrease matrix permeability with time. The lower sulfate concentration of the Terry Tunnel reference water (relative to the American Tunnel reference water) is offset by correspondingly elevated concentrations of metals. Consequently, the Terry Tunnel reference water is also essentially at equilibrium with major ore minerals and should be non-reactive with them along the migration path. There may be some dissolution of rhodochrosite, which would further neutralize the water and increase its buffering capacity.

Dilute, oxidized surface water that may enter the mine workings should be decreased in the future as a result of surface water diversions under construction above the mine workings. Any such water that does enter is expected to be driven toward reference water composition by dissolution of ore minerals it comes in contact with along the flow paths.

9.4 *Overall Chemistry of Impounded Water Expected to Move through the Ground-Water System*

Water within the flooded workings is anticipated to represent a mix of American Tunnel and Terry Tunnel reference waters. At deeper levels, chemistry similar to the American Tunnel reference water is expected to dominate, and at shallower levels the chemistry will be most like the Terry Tunnel reference water. Engineering efforts are being enacted to inhibit turnover within the flooded workings, so uniform mixing is less likely within the mine workings than is a somewhat stratified transition between end members. Further mixing between mine waters, and with ground water, is expected to occur as the water moves through the natural fracture system toward Cement Creek. Modeling of 4:1 and 1:1 (American Tunnel:Terry Tunnel) mixes of the reference waters indicates that much of the metals load is likely to precipitate out of solution within the mine workings, due to reducing conditions. This process is an analog to the natural processes of supergene enrichment of ore bodies. In order to be conservative, this likely precipitation was not permitted, and total metals load was retained. Hence, the modeling may yield a somewhat greater metals load than is expected.

9.5 *Anticipated Chemistry of Surface Discharge*

Surface discharge of the compounded water was simulated by equilibrating the reference waters and the two mixes of reference waters to atmospheric concentrations of CO_2 and O_2 and then permitting oversaturated minerals to precipitate. The suite of precipitated minerals, dominantly metal oxides (or

hydroxides) and carbonates, drops most of the metals from solution. This is analogous to the natural processes which form the iron "bogs" in the area. Table 11 shows the composition of the modeled discharge water for each of the reference waters and each of the modeled mixes.

9.6 Effects of Discharge on Cement Creek

The environmental impact of the surface drainage can be assessed in part by comparing the anticipated composition of the discharge to present surface water drainage into which the discharge will eventually flow. In this case, that surface drainage is Cement Creek. That comparison is made between the two modeled mixed waters and Cement Creek at periods of high and low flow in Table 12. Also included in Table 12 are the results of a flow-proportionate mix of the discharge waters with the creek waters at high and low discharge. There is no discernable impact on Cement Creek water quality that will result from mixing the modeled discharge waters with the surface drainage. The only significant difference between the waters is that the modeled discharge is of higher pH and contains considerably more carbonate buffering than Cement Creek. The result of such mixing could be to increase Cement Creek's buffering capacity and/or decrease the acidity of this stream.

Based upon the concentrations of the modeled discharge water and the probable discharge volume, with the conservative assumption of no other losses, such as adsorption of dissolved metals on precipitated oxides, the installation of these

Table 11. Modeled Discharge Water Quality

AMERICAN TUNNEL		4:1 MIX AMERICAN TUNNEL TO TERRY TUNNEL		1:1 MIX		TERRY TUNNEL	
MINTEQA2 Component	mg/L	MINTEQA2 Component	mg/L	MINTEQA2 Component	mg/L	MINTEQA2 Component	mg/L
SO_4--	926	SO_4--	850	SO_4--	735	SO_4--	544
CO_3--	33.9	CO_3-	33.4	CO_3--	13.9	CO_3--	0.77
Cl-	0.05	Cl-	0.10	Cl-	0.18	Cl-	0.30
F-	1.11	F-	1.00	F-	1.09	F-	5.56
Ca++	337	Ca++	361	Ca++	284	Ca++	160
Mg++	4.04	Mg++	7.03	Mg++	11.5	Mg++	19.0
Na+	3.00	Na+	2.74	Na+	2.35	Na+	1.70
Al+++	ND	Al+++	ND	Al+++	ND	Al+++	3.08
K+	0.05	K+	0.28	K+	0.63	K+	1.20
H_4SiO_4	ND	H_4SiO_4	ND	H_4SiO_4	ND	H_4SiO_4	ND
Fe+++	ND	Fe+++	ND	Fe+++	ND	Fe+++	ND
Mn++	ND	Mn++	ND	Mn++	ND	Mn++	ND
Zn++	0.97	Cu++	0.26	Cu++	0.24	Cu++	5.11
Sr++	3.79	Zn++	8.98	Zn++	22.5	Zn++	47.6
Cd++	0.006	Sr++	3.23	Sr++	2.38	Sr++	0.98
Pb++	0.025	Cd++	0.01	Cd++	0.04	Cd++	0.19
pH	7.87	Pb++	0.18	Pb++	0.44	Pb++	1.05
pE	13.81	pH	7.82	pH	7.82	pH	2.60
		pE	14.18	pE	14.18	pE	19.68
PRECIPITATED MINERALS:							
	mg precipitated per liter of solution		mg precipitated per liter of solution		mg precipitated per liter of solution		mg precipitated per liter of solution
Calcite	191.171	Pyrolusite	34.88	Pyrolusite	68.00	Pyrolusite	122.93
Pyrolusite	12.780	$ZnSiO_3$	8.55	Hematite	11.20	Hematite	16.78
$ZnSiO_3$	8.728	Hematite	6.55	$ZnSiO_3$	8.27	Ca-Nontronite	5.72
Fluorite	3.826	Fluorite	5.15	Fluorite	6.56		
Hematite	3.944	Tenorite	5.1	Diaspore	4.23		
Diaspore	1.338	ZnO (Active)	4.24	Brochantite	3.86		
Otavite	0.052	Diaspore	2.49	Otavite	0.12		
		Otavite	0.10	Cerussite	0.12		
		Plattnerite	0.06				

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sunny\wp\tracl\2251\Table11.WK3

Table 12. Comparison of modeled discharge water with chemistry of Cement Creek

Date	Source	Flow MGD	Field pH	Field Temp deg-C	Lab pH	Major Anions Sulfate	Bicarb	Fluoride	Chloride
05/31/89	Cement Creek	15.67	3.9	12.0	4.1	50		4.8	
07/02/87	Cement Creek	11.47	3.9	8.8	4.2	60	0.0	0.4	0.0
	4:1 Spring Wtr	0.11	7.8	9.0		850	33.4	1.0	0.1
	1:1 Spring Wtr	0.11	7.4	9.0		735	13.9	1.1	0.2
03/29/91	Cement Creek	0.32	4.2	5.0	4.5	462	0.0	2.2	3.1
02/11/91	Cement Creek	0.23	5.7	1.9	3.5	439	0.0	3.1	2.0

Date	Source	Major Cations Ca	Na	Mg	Al	K	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
05/31/89	Cement Creek	17	8.4	0.2	1.8	0.9	1.2	0.5	1.4	0.24	0.04	0.01
07/02/87	Cement Creek	16	1.0	4.0	0.8	0.0	0.7	1.0	3.8	0.13	ND	0.03
	4:1 Spring Wtr	361	2.7	7.0	0.0	0.3	0.0	0.0	9.0	0.26	0.18	0.01
	1:1 Spring Wtr	284	2.4	11.5	0.0	0.6	0.0	0.0	22.5	0.24	0.44	0.04
03/29/91	Cement Creek	147	2.3	14.1	5.2	0.6	0.3	6.8	6.0	0.26	0.25	0.02
02/11/91	Cement Creek	135	4.1	15.2	6.7	0.7	1.1	8.3	7.4	0.40	0.29	0.07

Cement Creek water quality after bulkhead installation:		Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Al	K
High flow and 4:1 mix	13.68	61	0.3	2.9	0.0	19	5.3	1.8	1.4	0.5
Low flow and 4:1 mix	0.385	566	9.5	2.1	1.9	205	3.0	12.4	4.2	0.5
High flow and 1:1 mix	13.68	60	0.1	2.9	0.0	19	5.2	1.9	1.4	0.5
Low flow and 1:1 mix	0.385	533	4.0	2.1	1.9	183	2.9	13.7	4.2	0.6

Cement Creek water quality after bulkhead installation:	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
High flow and 4:1 mix	1.0	0.7	2.4	0.19	0.02	0.02
Low flow and 4:1 mix	0.5	5.3	7.3	0.30	0.24	0.03
High flow and 1:1 mix	1.0	0.7	2.5	0.19	0.03	0.02
Low flow and 1:1 mix	0.5	5.3	11.1	0.30	0.32	0.04

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bulkheads should deliver the following metals load (lbs/day) to Cement Creek: iron, <.1; manganese, <.1; zinc, 8.1 to 20.3; cadmium, .009 to .036; lead, .16 to .40; and copper, .22 to .23.

9.7 Acid-Generating Potential of Wall Encrustations

The previous parts of Section 9 have considered the most likely effect that country rock and primary vein mineralization will have on impounded water and vice-versa. Secondary mineralization (encrustations on mine walls formed after tunnel construction) is considered in this section. At some other mines, wall encrustations have been shown to have significant acid-generating potential.

Coatings of secondary minerals are relatively rare on the walls of the accessible parts of the Sunnyside Mine. The general lack of secondary mineralization is probably due to the overall low permeability of the fractured volcanic rocks which results in mine walls being quite dry in most places.

During December, 1992, a Simon Hydro-Search hydrogeologist was taken to locations where SGC staff had remembered seeing mineral crusts on the walls of the mine. Mineral crusts were scraped from the walls and placed in rock sample bags for future analysis.

Table 13 summarizes the results of the analyses of the wall scrapings. The complete laboratory report including methodology is given in Appendix E. Wall scrapings from below B-level (nominal elevation of 12,250 feet) all had a paste pH of greater than 4.5. A paste pH represents a minimal amount of water added to a sample and will typically yield a worst case pH. A paste pH of greater than 4.5 indicates a very low potential for acid generation.

The three wall scrapings from B-level all had a paste pH of less than 4.0 and warranted further evaluation. Samples 1-5 were all mixed with a weakly buffered solution which simulated the measured buffering capacity of Terry Tunnel water. The solution resulting from sample 5 (from B-level) showed a pH of 5.7 after mixing with 100 parts of weakly buffered water to one part of sample. The solutions resulting from sample 4 showed a pH of 6.7 after mixing 1000 parts of weakly buffered water to one part of sample. The actual ratio of water filling the tunnels to volume of wall coatings is greater than 1000 to 1 even if only the immediate vicinities of the wall coatings are considered. The solution resulting from sample 3 had a pH of 4.9 after mixing 10,000 parts of weakly buffered water to one part of sample. The mineral encrustation where sample 3 was taken covered an area of only 2 by 6 feet, so only a small volume of mine workings would have to be flooded to counteract the effects of this zone. If the full volume of the mine is considered, the acid-generating capacity of the observed wall scrapings is insignificant.

Table 13: Acid-Generating Potential of Mineral Encrustations on Walls

Sample Number	Location	Paste pH	Slurry pH 1 part sample in 100 parts of solution	Slurry pH 1 part sample in 1000 parts of solution	Slurry pH 1 part sample in 10,000 parts of solution
1	F-Level, 100' East of proposed bulkhead site	4.62	6.60	---	---
2	F-Level Brenneman vein localized, brown-black mud flowstone, located 100 feet toward Washington Shaft from proposed bulkhead	6.10	6.05	---	---
3	B-Level, near proposed bulkhead site, localized white flowstone 2 x 6 foot zone	2.49	2.75	3.6	4.9
4	B-Level, near proposed bulkhead, ¼" thick local deposit, brown flowstone	3.11	3.45	6.7	---
5	B-Level, Washington Vein near Washington vertical shaft-wall scraping 1/16" thick	3.56	5.70	---	---
6	D-Level, wall scrape, 2700 stope, localized flowstone	6.50	---	---	---

The only observed secondary mineralization with acid-generating potential was on B-level at an elevation of approximately 12,250 feet msl. The expected equilibrium water level of the flooded mine workings (if surface water inflow to the mine from Sunnyside Basin is largely abated) is just below F-level. Hence, all of the sampled mineral crusts are expected to be above the equilibrium water level. The only observed mineral crusts with significant acid-generating capacity were at an elevation of 12,250 feet: over 700 feet higher than the expected equilibrium water level. Hence, stored acidity in secondary mineralization is not expected to be a significant problem.

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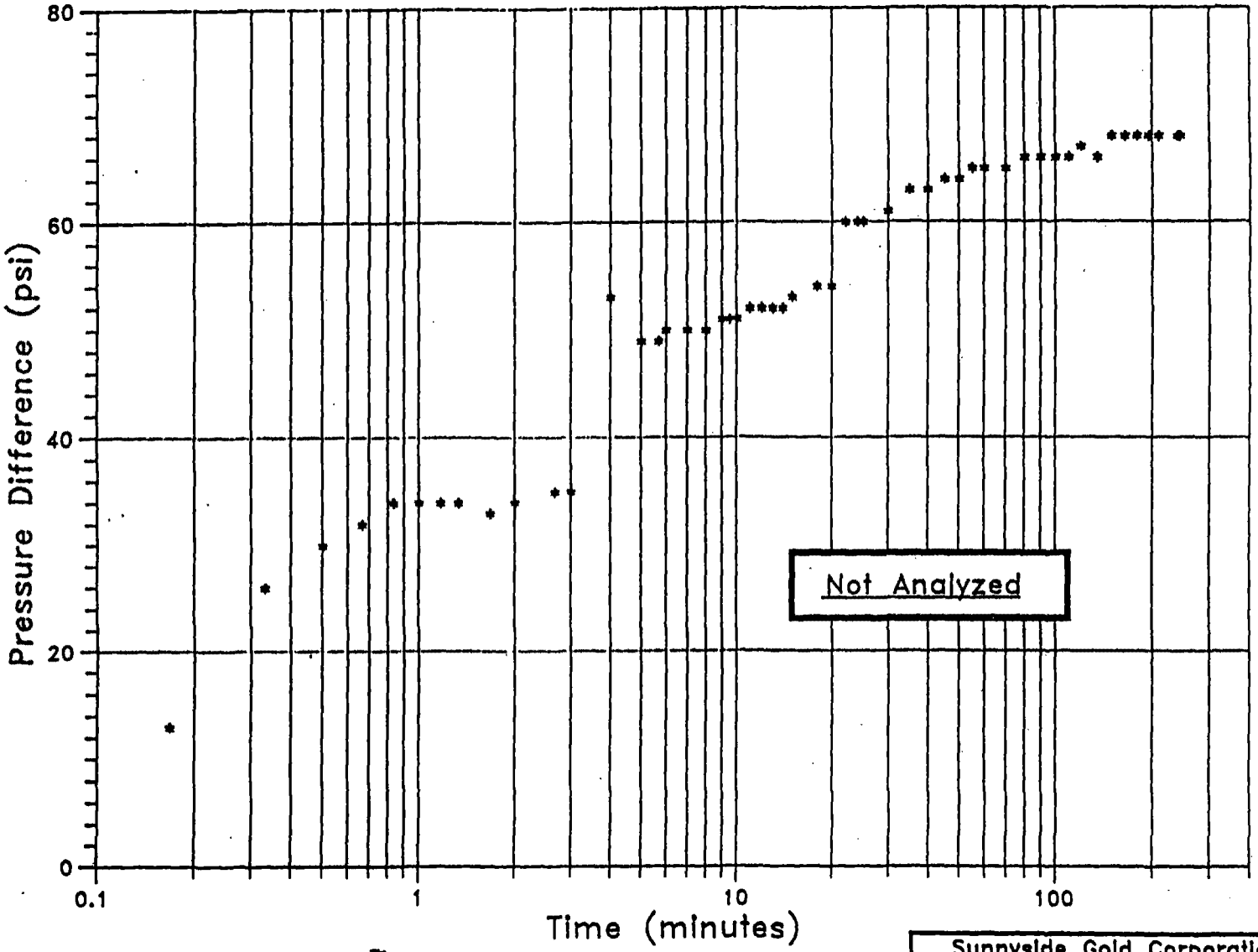
APPENDIX A

Results of Flow Testing in the American Tunnel



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SIMON HYDRO-SEARCH	Figure A-1

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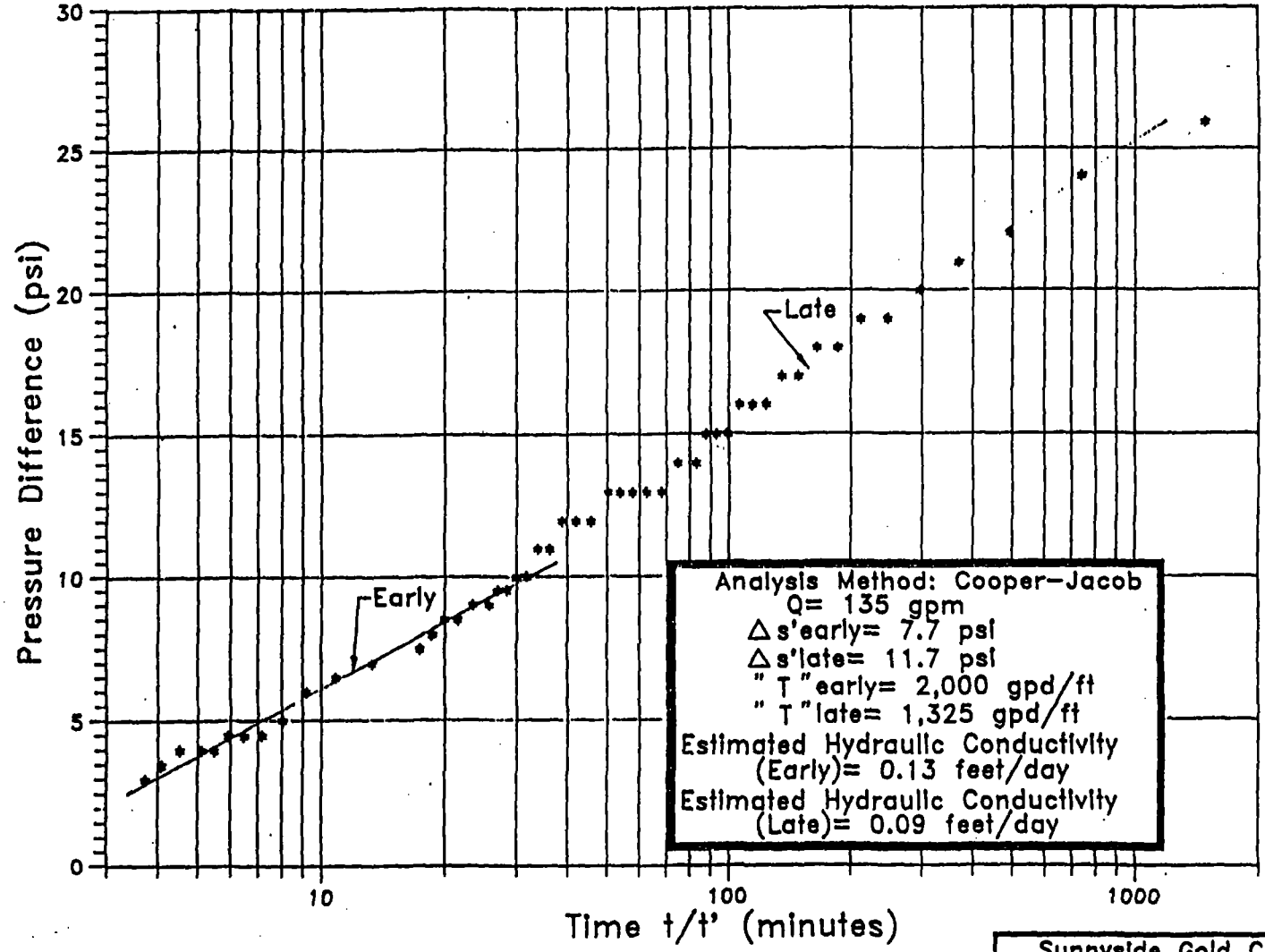

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SIMON HYDRO-SEARCH	Figure A-2

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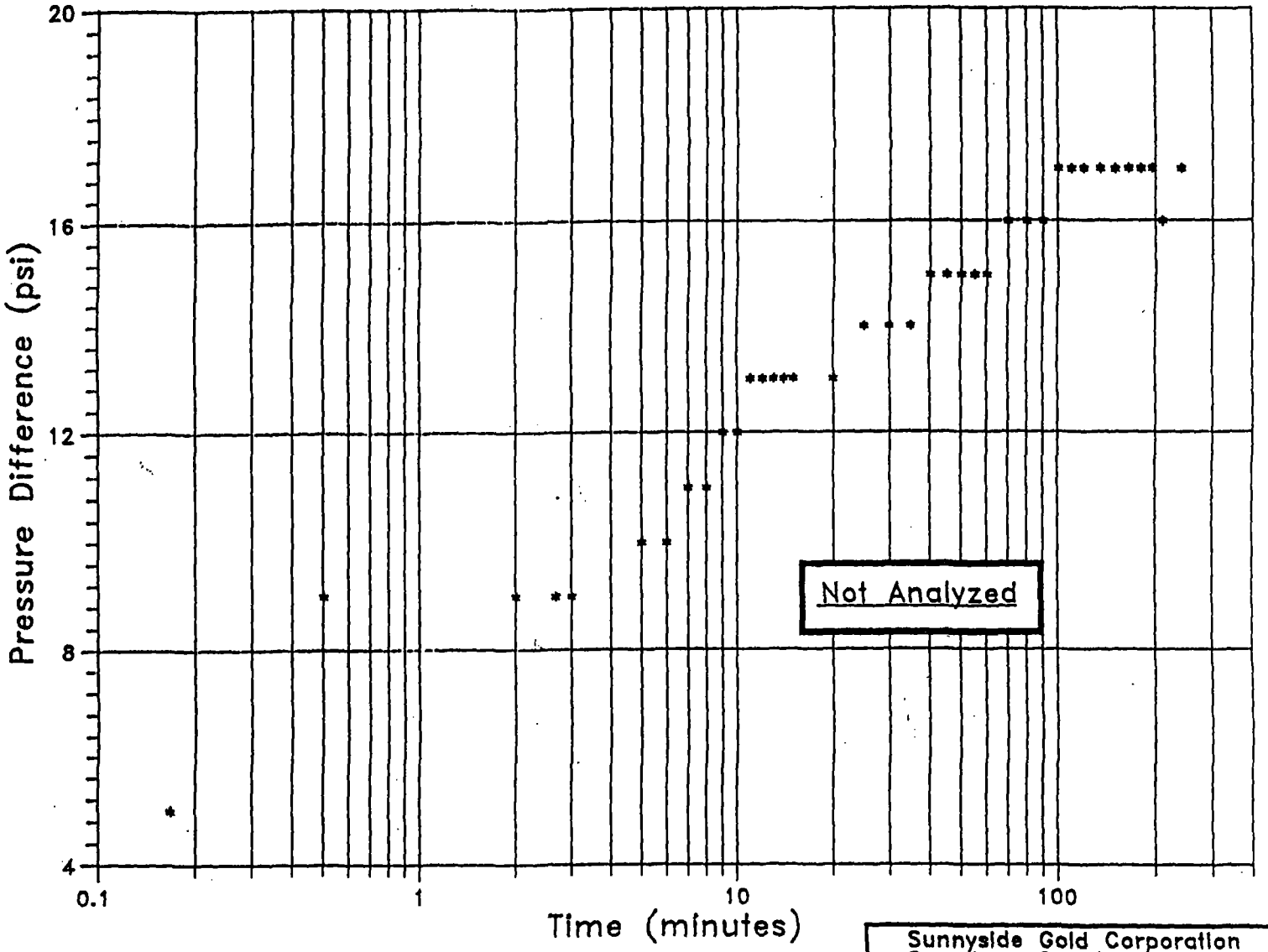

Sunnyside Gold Corporation San Juan County, Colorado	DATE: 03/05/93 DESIGNED: ROW CHECKED: RGB APPROVED: DRAWN: RJJ PROJ.: 187112251
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SIMON HYDRO-SEARCH	Figure A-3

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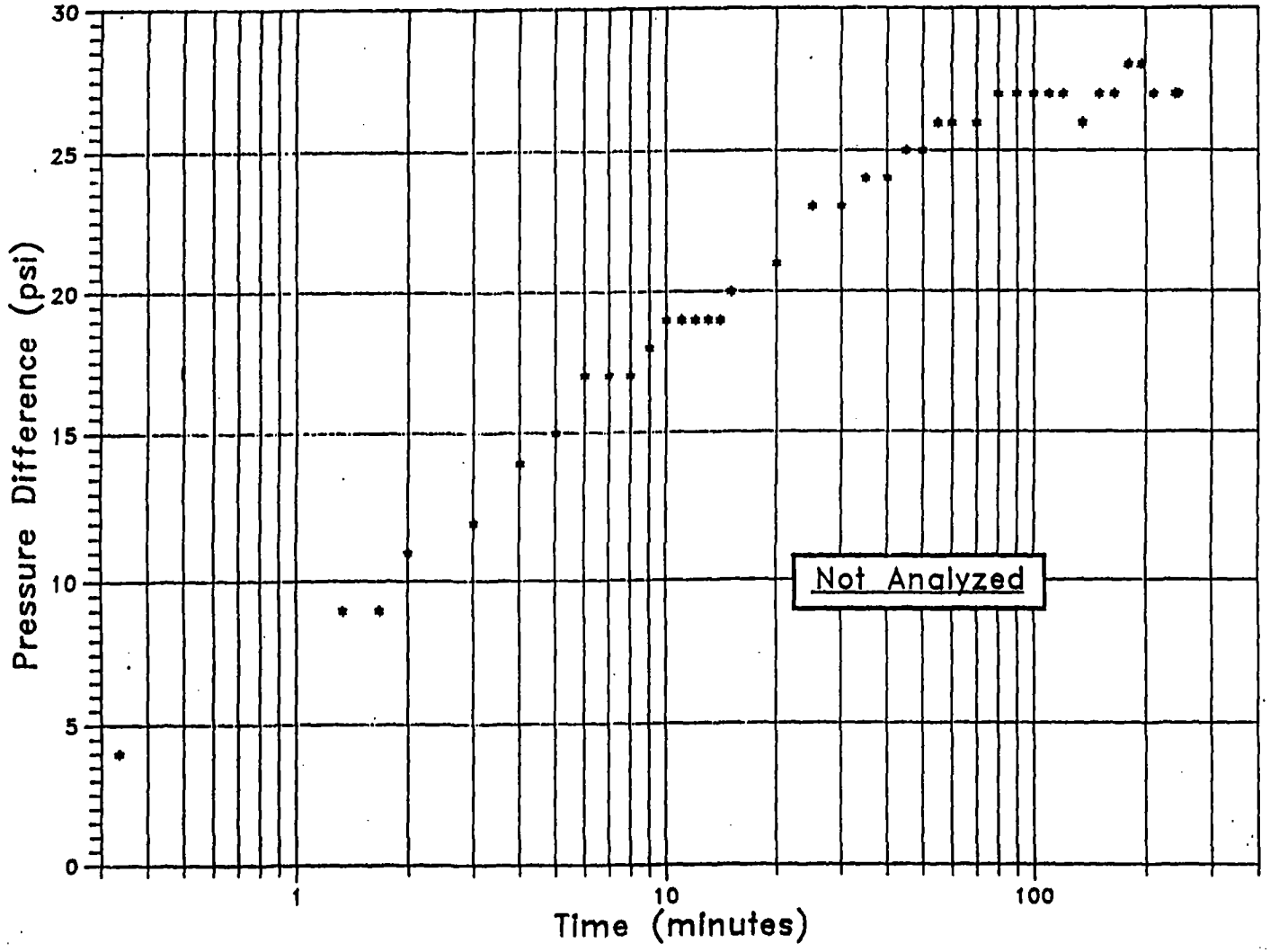

Sunnyside Gold Corporation San Juan County, Colorado	DATE: 03/05/93
704 Hole Drawdown Test	DESIGNED: ROW CHECKED: RGB APPROVED: DRAWN: RJJ PROJ.: 187112251
SIMON HYDRO-SEARCH	Figure A-4

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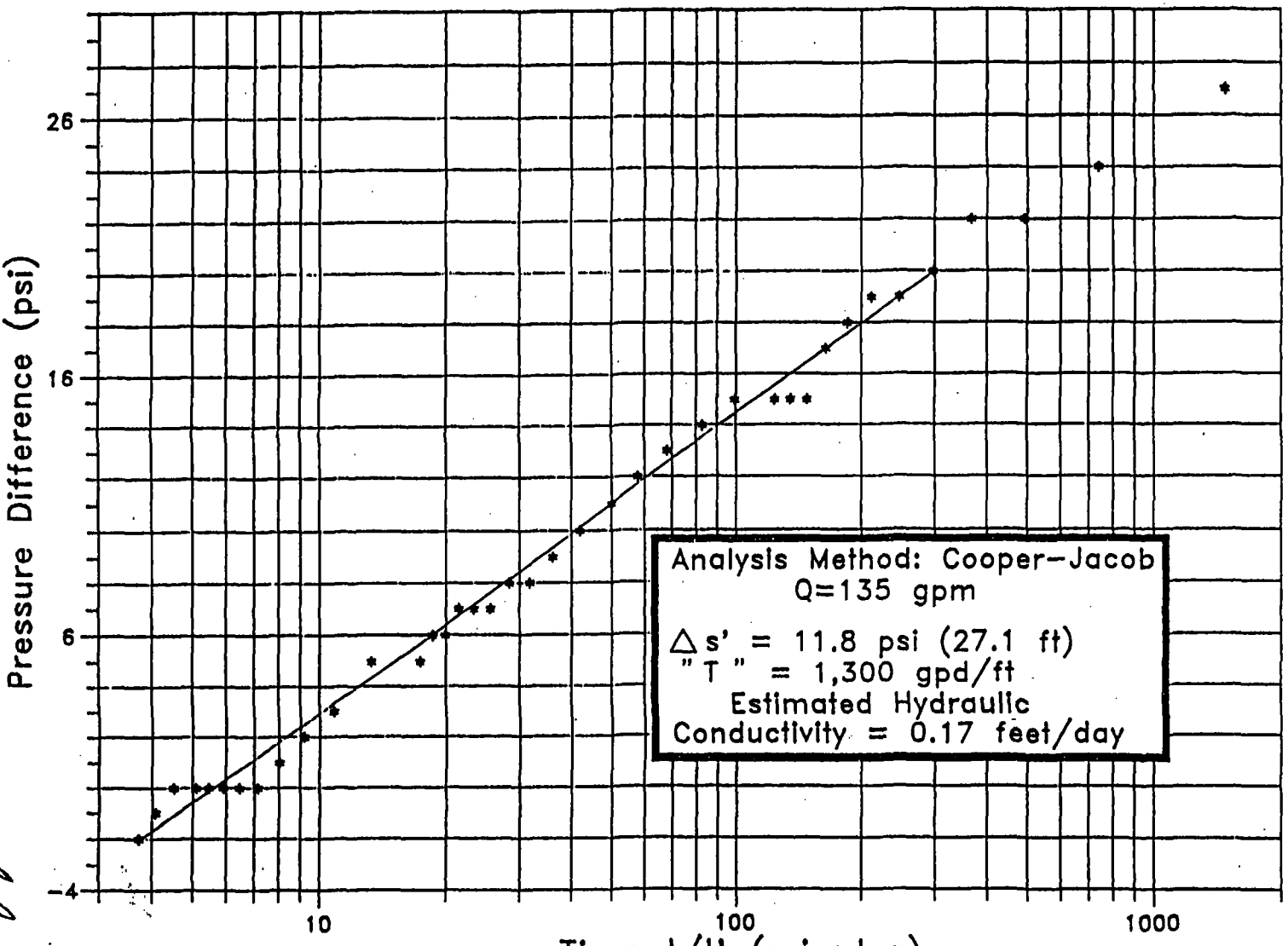

Parallel plate model

1300
d^2 x viscosity

Sunnyside Gold Corporation San Juan County, Colorado	DATE: 03/06/93
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704 Hole Recovery Test	CHECKED: RGB
	APPROVED:
	DRAWN: RAS
	PROJ.: 187112251
SIMON HYDRO-SEARCH	Figure A-5

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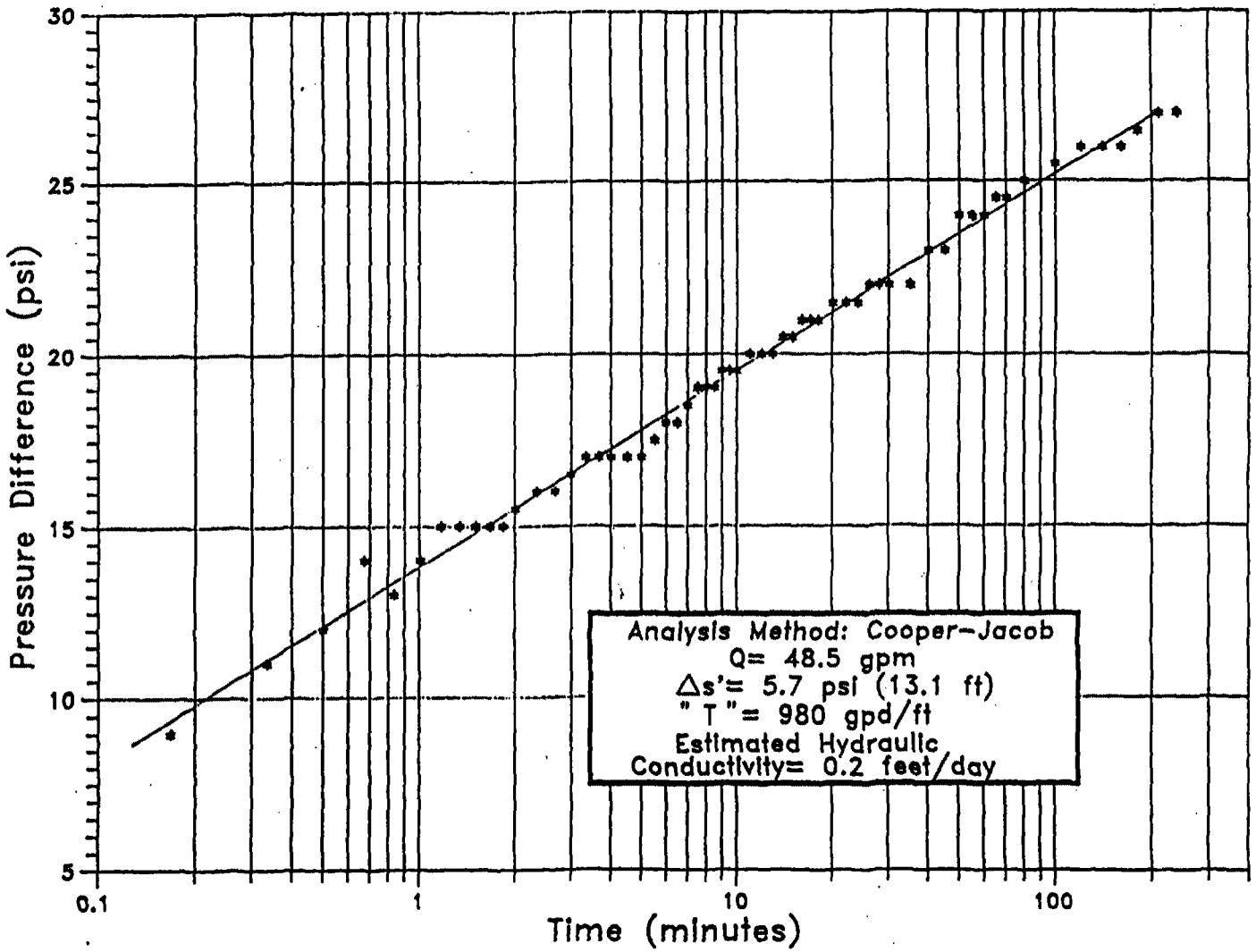

Sunnyside Gold Corporation San Juan County, Colorado	DATE: 03/05/93
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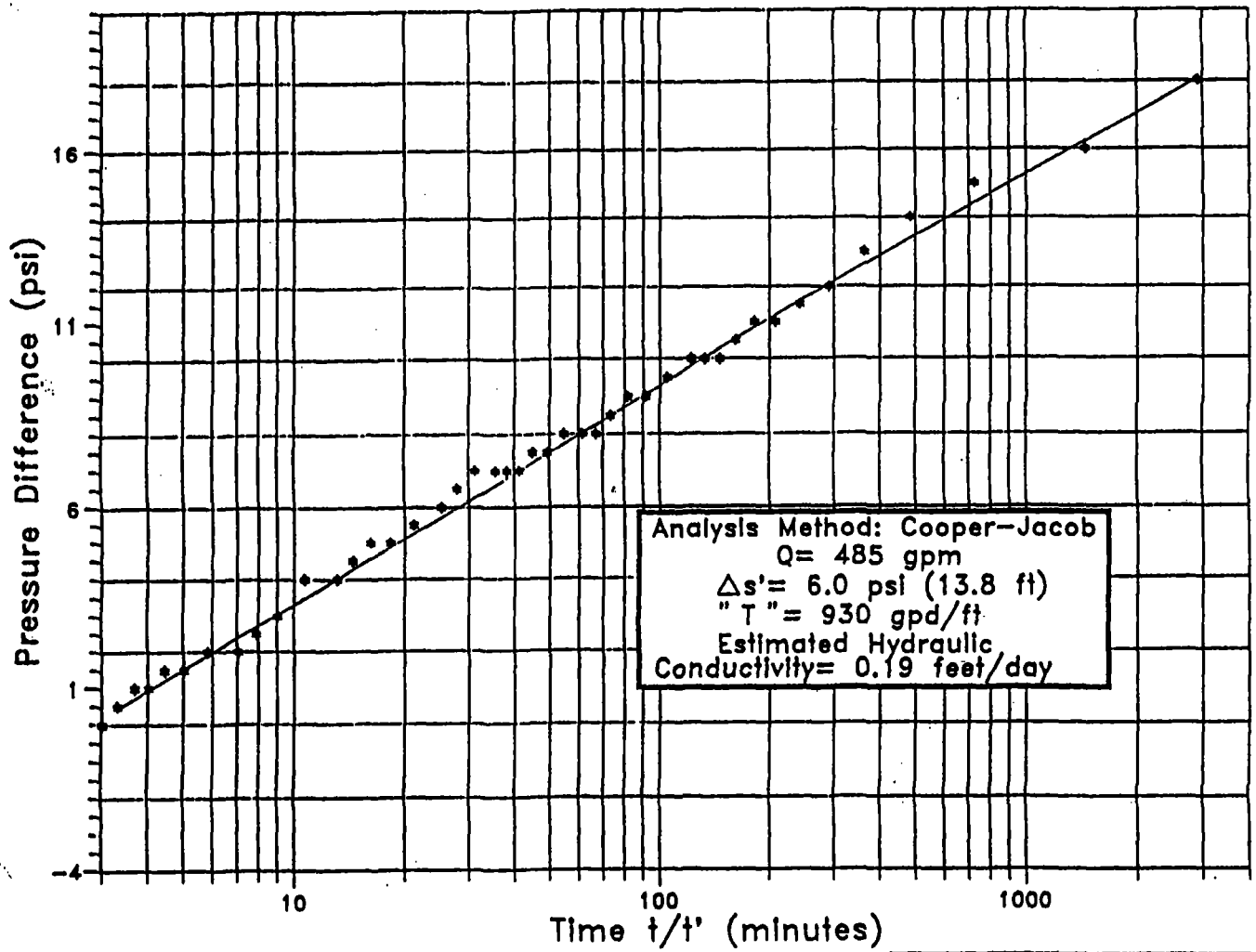
HSI SIMON HYDRO GRADE	Figure A-6



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781 Hole Recovery Test	
SIMON HYDRO-SEARCH	Figure A-7

ED_000552B_00064447-00087

APPENDIX B

Volume of Sunnyside Mine Workings

SUNNYSIDE GOLD CORPORATION
AN ECHO BAY COMPANY

P.O. Box 177 • Silverton, CO 81433
Phone (303) 387-5533 • Telecopy (303) 387-5310

RECEIVED
JAN 19 1993

January 13, 1993

Mark D. Stock, Hydrogeologist
Simon Hydro-Search
5250 South Virginia Street
Reno, Nevada 89502

Dear Mark,

Per your request, please find attached the calculation for mined volumes at Sunnyside Mine. The calculation starts at the lowest workings of the mine, American Tunnel level, and is calculated at 100 foot elevations starting at 10,700 feet, for open workings below that elevation. The calculation stops at 12,210 feet or the elevation of the surface diversion ditch around the former Lake Emma.

The 80 scale engineering vein sections were used as a base source of information for the calculations. The area was calculated using a planimeter. The area was multiplied by average widths from geologic mapping and engineering measurements where available. When no width information was available, the stope widths were extrapolated from adjacent stopes. The volumes listed are cubic feet.

Cut and fill stopes in which waste rock was used for fill, calculated volume was multiplied by a 50% factor to allow for the volume consumed by fill.

Flat lying vein systems were mathematically corrected in order to reflect true volumes.

The waste drift volumes were calculated from horizontal measurements on 200 scale engineering plans and multiplied by average drift profiles on each level. Miscellaneous volumes such as shops, cutouts and hoistrooms were added to this calculation. The volumes listed are cubic feet.

The volumes are summarized by vein section or drifts for volume necessary to reach the elevation listed. There are also summaries for cumulative cubic feet to reach elevation, gallons added per 100 feet increase in elevation and cumulative gallons necessary to reach an elevation.

If you need additional information please call.

Sincerely,

William B. Goodhard

cc: Larry Perino

SUNNYSIDE GOLD CORPORATION
SUNNYSIDE MINE
WATER VOLUMES BY ELEVATION (cu.ft.)

	ELEVATION															
VEIN SECTION	10660 to 10700	10700 to 10800	10800 to 10900	10900 to 11000	11000 to 11100	11100 to 11200	11200 to 11300	11300 to 11400	11400 to 11500	11500 to 11600	11600 to 11700	11700 to 11800	11800 to 11900	11900 to 12000	12000 to 12100	12100 to 12210
1900	0	0	0	0	0	40,960	512	136,192	152,320	528,640	465,920	483,840	98,560	0	0	
LITTLE MARY	0	0	0	0	0	0	0	97,920	282,240	282,810	1,111,040	816,000	647,680	232,128	151,168	24,57
SUNNYSIDE	0	0	0	0	0	0	0	0	0	92,700	504,440	169,200	616,640	294,560	412,880	549,12
WASHINGTON	308,040	2,448,320	2,679,120	1,793,120	1,280,040	881,640	1,403,200	773,440	1,864,000	1,391,920	2,119,200	1,900,800	1,908,800	1,777,600	1,206,400	919,60
BELLE CREOLE	110,880	355,040	381,360	280,448	184,880	132,400	53,520	86,800	251,440	261,520	597,760	421,280	429,040	521,200	398,840	195,76
2150 FOOTWALL	0	0	0	0	0	60,800	492,160	539,760	1,657,952	1,140,608	2,394,160	998,800	964,160	746,400	568,800	
2150 EXIT	0	0	0	0	0	0	230,300	423,000	1,187,500	1,211,000	675,600	241,280	0	0	0	
2150 HANGING WALL	0	0	0	0	0	0	0	5,600	389,120	546,380	486,240	403,280	32,400	0	0	
SPUR	0	0	0	0	0	0	0	0	0	124,840	915,370	534,300	1,048,704	750,400	407,104	178,1
SPUR SPLIT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	116,320	138,2
SPUR WEST	0	0	0	0	0	0	0	186,300	253,600	95,280	0	0	0	0	0	
2250	0	0	0	0	0	0	0	25,920	124,488	109,738	314,665	196,880	245,280	67,200	0	
MOUNTAIN SHEEP	0	0	0	0	0	0	0	40,320	120,960	11,200	0	0	0	0	0	
PORTLAND FW EAST	0	0	0	0	0	0	0	76,028	214,177	300,721	285,378	37,200	105,152	0	0	
PORTLAND FW WEST	0	0	0	0	0	0	0	0	319,336	375,558	135,764	0	0	0	0	
PORTLAND BX EAST	0	0	0	0	0	0	55,152	347,898	342,046	223,132	85,367	19,200	0	0	0	
PORTLAND BX WEST	0	0	0	0	0	0	96,000	272,668	671,882	312,275	0	0	0	0	0	
JOKER	0	0	0	0	0	0	0	0	0	0	0	0	82,950	0	0	10,
NO NAME	0	0	0	0	0	0	0	0	0	73,200	930,290	573,440	234,880	10,720	5,600	325,
DRIFTS AND MISC	1,012,960	0	0	0	0	0	98,000	898,530	0	1,083,060	67,412	1,264,617	137,520	0	236,360	127,
TOTAL	1,431,880	2,803,360	3,060,480	2,073,568	1,464,920	1,115,800	2,428,844	3,910,376	7,831,061	8,164,582	11,088,606	8,060,117	6,551,766	4,400,208	3,503,472	2,469,

SUNNYSIDE GOLD CORPORATION
SUNNYSIDE MINE
WATER VOLUMES BY ELEVATION (cu.ft.)

CUMULATIVE VOLUME (cu.ft.) TO FILL TO ELEVATION LISTED

VEIN SECTION	10700	10800	10900	11000	11100	11200	11300	11400	11500	11600	11700	11800	11900	12000	12100	1221(
1900	0	0	0	0	0	40,960	41,472	177,664	329,984	858,624	1,324,544	1,808,384	1,906,944	1,906,944	1,906,944	1,906,94
LITTLE MARY	0	0	0	0	0	0	0	97,920	380,160	662,970	1,774,010	2,590,010	3,237,690	3,469,818	3,620,986	3,645,56
SUNNYSIDE	0	0	0	0	0	0	0	0	0	92,700	597,140	766,340	1,382,980	1,677,540	2,090,420	2,639,54
WASHINGTON	308,040	2,756,360	5,435,480	7,228,600	8,508,640	9,390,280	10,793,480	11,566,920	13,430,920	14,822,840	16,942,040	18,842,840	20,751,640	22,529,240	23,735,640	24,655,24
BELLE CREOLE	110,880	465,920	847,280	1,127,728	1,312,608	1,445,008	1,498,528	1,585,328	1,836,768	2,098,288	2,696,048	3,117,328	3,546,368	4,067,568	4,466,408	4,662,16
2150 FOOTWALL	0	0	0	0	0	60,800	552,960	1,092,720	2,750,672	3,891,280	6,285,440	7,284,240	8,248,400	8,994,800	9,563,600	9,563,60
2150 EXT	0	0	0	0	0	0	230,300	653,300	1,840,800	3,051,800	3,727,400	3,968,680	3,968,680	3,968,680	3,968,680	3,968,68
2150 HANGING WALL	0	0	0	0	0	0	0	5,600	394,720	941,100	1,427,340	1,830,620	1,863,020	1,863,020	1,863,020	1,863,02
SPUR	0	0	0	0	0	0	0	0	0	124,840	1,040,210	1,574,510	2,623,214	3,373,614	3,780,718	3,958,8
SPUR SPLIT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	116,320	254,5
SPUR WEST	0	0	0	0	0	0	0	186,300	439,900	535,180	535,180	535,180	535,180	535,180	535,180	535,1
2250	0	0	0	0	0	0	0	25,920	150,408	260,146	574,811	771,691	1,016,971	1,084,171	1,084,171	1,084,1
MOUNTAIN SHEEP	0	0	0	0	0	0	0	40,320	161,280	172,480	172,480	172,480	172,480	172,480	172,480	172,4
PORTLAND FW EAST	0	0	0	0	0	0	0	76,028	290,205	590,926	876,304	913,504	1,018,656	1,018,656	1,018,656	1,018,6
PORTLAND FW WEST	0	0	0	0	0	0	0	0	319,336	694,894	830,658	830,658	830,658	830,658	830,658	830,6
PORTLAND BX EAST	0	0	0	0	0	0	55,152	403,050	745,096	968,228	1,053,595	1,072,795	1,072,795	1,072,795	1,072,795	1,072,7
PORTLAND BX WEST	0	0	0	0	0	0	96,000	368,668	1,040,550	1,352,825	1,352,825	1,352,825	1,352,825	1,352,825	1,352,825	1,352,8
JOKER	0	0	0	0	0	0	0	0	0	0	0	0	82,950	82,950	82,950	93,7
NO NAME	0	0	0	0	0	0	0	0	0	73,200	1,003,490	1,576,930	1,811,810	1,822,530	1,828,130	2,153,8
DRIFTS AND MISC	1,012,960	1,012,960	1,012,960	1,012,960	1,012,960	1,012,960	1,110,960	2,009,490	2,009,490	3,092,550	3,159,962	4,424,579	4,562,099	4,562,099	4,798,459	4,925,8
TOTAL	1,431,880	4,235,240	7,295,720	9,369,288	10,834,208	11,950,008	14,378,852	18,289,228	26,120,289	34,284,871	45,373,477	53,433,594	59,985,360	64,385,568	67,883,040	70,358,4

SUNNYSIDE GOLD CORPORATION
SUNNYSIDE MINE
WATER VOLUMES BY ELEVATION (gal.)

GALLONS OF WATER TO FILL TO ELEVATION LISTED

VEIN SECTION	10700	10800	10900	11000	11100	11200	11300	11400	11500	11600	11700	11800	11900	12000	12100	122
1900	0	0	0	0	0	306,381	3,830	1,018,716	1,139,354	3,954,227	3,485,082	3,619,123	737,229	0	0	
LITTLE MARY	0	0	0	0	0	0	0	732,442	2,111,155	2,115,419	8,310,579	6,103,680	4,844,646	1,736,317	1,130,737	183,8
SUNNYSIDE	0	0	0	0	0	0	0	0	0	693,396	3,773,211	1,265,616	4,612,467	2,203,309	3,088,342	4,107,4
WASHINGTON	2,304,139	18,313,434	20,039,818	13,412,538	9,574,699	6,594,667	10,495,936	5,785,331	13,942,720	10,411,562	15,851,616	14,217,984	14,277,824	13,296,448	9,023,872	6,878,6
BELLE CREOLE	829,382	2,655,699	2,852,573	2,097,751	1,382,902	990,352	400,330	649,264	1,880,771	1,956,170	4,471,245	3,151,174	3,209,219	3,898,576	2,983,323	1,464,2
2150 FOOTWALL	0	0	0	0	0	454,784	3,681,357	4,037,405	12,401,481	8,531,748	17,908,317	7,471,024	7,211,917	5,583,072	4,254,624	
2150 EXT	0	0	0	0	0	0	1,722,644	3,164,040	8,882,500	9,058,280	5,053,488	1,804,774	0	0	0	
2150 HANGING WALL	0	0	0	0	0	0	0	41,888	2,910,618	4,086,922	3,637,075	3,016,534	242,352	0	0	
SPUR	0	0	0	0	0	0	0	0	0	933,803	6,846,968	3,996,564	7,844,306	5,612,992	3,045,138	1,232,7
SPUR SPLIT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	870,074	1,034,0
SPUR WEST	0	0	0	0	0	0	0	1,393,524	1,896,928	712,694	0	0	0	0	0	
2250	0	0	0	0	0	0	0	193,882	931,170	820,840	2,353,694	1,472,662	1,834,694	502,656	0	
MOUNTAIN SHEEP	0	0	0	0	0	0	0	301,594	904,781	83,776	0	0	0	0	0	
PORTLAND FW EAST	0	0	0	0	0	0	0	568,689	1,602,044	2,249,393	2,134,627	278,256	786,537	0	0	
PORTLAND FW WEST	0	0	0	0	0	0	0	0	0	2,388,633	2,809,174	1,015,515	0	0	0	
PORTLAND BX EAST	0	0	0	0	0	0	412,537	2,602,277	2,558,504	1,669,027	638,545	143,616	0	0	0	
PORTLAND BX WEST	0	0	0	0	0	0	718,080	2,039,557	5,025,677	2,335,817	0	0	0	0	0	
JOKER	0	0	0	0	0	0	0	0	0	0	0	0	620,466	0	0	80,6
NO NAME	0	0	0	0	0	0	0	0	0	547,536	6,958,569	4,289,331	1,756,902	80,186	41,888	2,436,2
DRIFTS AND MISC	7,576,941	0	0	0	0	0	733,040	6,721,004	0	8,101,289	504,242	9,459,335	1,028,650	0	1,767,973	952,6
TOTAL	10,710,462	20,969,133	22,892,390	15,510,289	10,957,602	8,346,184	18,167,753	29,249,612	58,576,336	61,071,073	82,942,773	60,289,675	49,007,210	32,913,556	26,205,971	18,470,4

SUNNYSIDE GOLD CORPORATION
SUNNYSIDE MINE
CUMULATIVE WATER VOLUMES BY ELEVATION (gal.)

CUMULATIVE GALLONS OF WATER TO FILL TO ELEVATION LISTED

VEIN SECTION	10700	10800	10900	11000	11100	11200	11300	11400	11500	11600	11700	11800	11900	12000	12100	12
1900	0	0	0	0	0	306,381	310,211	1,328,927	2,468,260	6,422,508	9,907,589	13,526,712	14,263,941	14,263,941	14,263,941	14,263,
LITTLE MARY	0	0	0	0	0	0	0	732,442	2,843,597	4,959,016	13,269,595	19,373,275	24,217,921	25,954,239	27,084,975	27,268,
SUNNYSIDE	0	0	0	0	0	0	0	0	0	693,396	4,466,607	5,732,223	10,344,690	12,547,999	15,636,342	19,743,
WASHINGTON	2,304,139	20,617,573	40,657,390	54,069,928	63,644,627	70,239,294	80,735,230	86,520,562	100,463,282	110,874,843	126,726,459	140,944,443	155,222,267	168,518,715	177,542,587	184,421,
BELLE CREOLE	829,382	3,485,082	6,337,654	8,435,405	9,818,308	10,808,660	11,208,989	11,858,253	13,739,025	15,695,194	20,166,439	23,317,613	26,526,833	30,425,409	33,408,732	34,873,
2150 FOOTWALL	0	0	0	0	0	454,784	4,136,141	8,173,546	20,575,027	29,106,774	47,015,091	54,486,115	61,698,032	67,281,104	71,535,728	71,535,
2150 EXT	0	0	0	0	0	0	1,722,644	4,886,684	13,769,184	22,827,464	27,880,952	29,685,726	29,685,726	29,685,726	29,685,726	29,685,
2150 HANGING WALL	0	0	0	0	0	0	0	41,888	2,952,506	7,039,428	10,676,503	13,693,038	13,935,390	13,935,390	13,935,390	13,935,
SPUR	0	0	0	0	0	0	0	0	0	933,803	7,780,771	11,777,335	19,621,641	25,234,633	28,279,771	29,612,
SPUR SPLIT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	870,074	1,904,
SPUR WEST	0	0	0	0	0	0	0	1,393,524	3,290,452	4,003,146	4,003,146	4,003,146	4,003,146	4,003,146	4,003,146	4,003,
2250	0	0	0	0	0	0	0	193,882	1,125,052	1,945,892	4,299,586	5,772,249	7,606,943	8,109,599	8,109,599	8,109,
MOUNTAIN SHEEP	0	0	0	0	0	0	0	301,594	1,206,374	1,290,150	1,290,150	1,290,150	1,290,150	1,290,150	1,290,150	1,290,
PORTLAND FW EAST	0	0	0	0	0	0	0	568,689	2,170,733	4,420,126	6,554,754	6,833,010	7,619,547	7,619,547	7,619,547	7,619,
PORTLAND FW WEST	0	0	0	0	0	0	0	0	2,388,633	5,197,807	6,213,322	6,213,322	6,213,322	6,213,322	6,213,322	6,213,
PORTLAND BX EAST	0	0	0	0	0	0	412,537	3,014,814	5,573,318	7,242,345	7,880,891	8,024,507	8,024,507	8,024,507	8,024,507	8,024,
PORTLAND BX WEST	0	0	0	0	0	0	718,080	2,757,637	7,783,314	10,119,131	10,119,131	10,119,131	10,119,131	10,119,131	10,119,131	10,119,
JOKER	0	0	0	0	0	0	0	0	0	0	0	0	620,466	620,466	620,466	701,
NO NAME	0	0	0	0	0	0	0	0	0	547,536	7,506,105	11,795,436	13,552,339	13,632,524	13,674,412	16,110,
DRIFTS AND MISC	7,576,941	7,576,941	7,576,941	7,576,941	7,576,941	7,576,941	8,309,981	15,030,985	15,030,985	23,132,274	23,636,516	33,095,851	34,124,501	34,124,501	35,892,473	36,845,
TOTAL	10,710,462	31,679,595	54,571,986	70,082,274	81,039,876	89,386,060	107,553,813	136,803,425	195,379,762	256,450,835	339,393,608	399,683,283	448,690,493	481,604,049	507,810,019	526,280,

APPENDIX C

Details of Geochemical Modeling

C-1 AMERICAN TUNNEL

C-1.1 Overview

The installation of a bulkhead in the American Tunnel at Sunnyside Mine will impound water and flood the mine workings to an estimated equilibrium water level of 11,500 feet msl (see Section 3.3). As the water levels rise in the mine workings, water from the flooded workings is expected to begin to move through natural fracture systems to discharge zones along Cement Creek. A minor amount of water may also move around the bulkhead through country rock adjacent to the mine tunnel. Geochemical modeling was used to assess: 1) the nature of the water that would be impounded behind the proposed bulkhead, 2) what reactions, if any, may occur within country rock as water migrates around the bulkhead, 3) what reactions may impact the impounded water or the minerals along the migration path to the surface, and 4) the character of the water that eventually results from surface discharge.

Very little water from the workings above F-level drops to lower levels and exits through the American Tunnel. Water that currently discharges from the American Tunnel is ground water that enters the mine in response to the hydraulic gradient developed by dewatering the mine workings. The water that will be impounded by the American Tunnel bulkhead is expected to be similar to ground water which is currently flowing into the mine from fractures. It is further conceptualized that that water will eventually reach the ground surface and equilibrate with atmospheric gases, precipitating a suite of oversaturated minerals. Changes in mineral precipitates or fluid

composition behind the bulkhead and along the flow paths will be discussed only qualitatively due to limitations in the model.

C-1.2 Data

Most of the analyses from the mine waters were restricted to metals of concern for environmental and permitting purposes. However, a total of 14 water samples collected upstream of the proposed bulkhead in the American Tunnel were analyzed for major ions, minor constituents, and trace elements. Of these, all but four were samples taken from the drainage ditch of the American Tunnel. One sample was taken at a spring in the Sunnyside Cross Cut (before mixing with other water had occurred), and three were taken from two drill holes (#778 and #781) that had been extended into the American Tunnel walls. Eight of the samples are from mine drifts and may be a mixture of ground water and oxygenated water trickling down stopes. Analyses of the waters are shown in Table A-1.

The drill holes extend hundreds of feet back into the country rock, intersect non-ore mineralized fractures and are uncased. These four samples collected from the drill holes appear to be the most representative of the ground water in the fractured volcanic rock surrounding the mine.

The drill hole waters are very similar in overall character. The field pH is essentially neutral at 7.3 to 7.5 and field measurements showed no dissolved oxygen. The

dominant anions are sulfate and bicarbonate. Calcium is the dominant cation and there is a moderate dissolved metals load. Analytical ion balance for major elements was within one or two percent.

Iron and manganese concentrations are consistent among the waters from the drill holes, but zinc concentrations are quite variable. The waters are characterized by relatively high fluoride and strontium concentrations and low concentrations of lead and cadmium. Copper, mercury, arsenic, boron, gold, selenium and silver are all at or below detection limits for these elements.

Four analyses of total metals were also available for samples from each of the two bedrock drill holes. These showed consistent results with the whole water analyses for most metals. Zinc and manganese showed the greatest variation, varying from below detection to greater than 10 mg/l for each element.

C-1.3 American Tunnel Reference Water

This section describes MINTEQA2 simulations which were used to define the American Tunnel reference water. This reference water is the best characterization of the in-situ ground water that can be developed from the available analytic, geochemical, geologic and petrographic data. The geology, mineralogy, chemical analyses and geochemistry were integrated to define the best approximation of ground-water characteristics within the fractured volcanic bedrock around the

American Tunnel. Conceptually, this water collects behind the bulkhead, moves through the bedrock around the bulkhead, and moves through the natural fracture system. This water is expected to discharge to the surface, equilibrate with the atmosphere and potentially mix with surface drainage.

The water from drill hole #778 (also known as the 0700 North drill hole) was selected as the type analysis for major ion chemistry. This drill hole extends the furthest into the country rock and the water analyzed best represents an average from the greatest volume of rock. The analysis used was for the sample collected on 10/07/91. A second, recent sample, collected 01/04/93, demonstrates the overall consistency of the water chemistry with time. Both of these analyses are contained in Table A-1. The anion analyses from 10/07/91 for sulfate, bicarbonate and fluoride were used as input into MINTEQA2. The cation analyses used for model input were those for calcium, magnesium, sodium, aluminum and strontium. To ensure appropriate mineral and aqueous species assemblages were considered, potassium and chloride were included in the modeling analysis at 50% of the reported detection limit.

The metal concentrations used for defining the American Tunnel reference water were an average of the detections among the four total metal samples and the whole water sample. In each case, the model input concentrations were greater than that of the sample from drill hole 778. MINTEQA2 has the capability to calculate redox speciation for some elements. Three redox pairs were included in the model run, HS^-

/$SO_4^=$, Fe^{++}/Fe^{+++}, and Mn^{++}/Mn^{+++}, with the stipulation that they exhibit a common oxidation state. Because copper was at or below the detection limit for all samples from drill holes, the Cu^{+}/Cu^{++} redox pair was not included in the American Tunnel modeling.

An initial equilibration run of MINTEQA2 using field-measured pH and atmospheric equilibration with oxygen modeled oversaturation with respect to CO_2 and calcite. Based upon probable ground-water flow paths and petrographic data, it is geologically likely that the on-site ground water is at or near equilibrium with calcite, but probably not oversaturated.

This model run, and all subsequent model runs, assumed appropriate in-situ temperatures. The field pH, the bicarbonate concentration, and the oversaturation of the analytic composition of the water with respect to calcite are believed to be, in part, artifacts of sampling procedures. Ground water sampled at the 778 borehole is under approximately 10 atmospheres of pressure. The release of this pressure with a concomitant exsolution of CO_2 equilibrating the $P(CO_2)$ of the solution to atmospheric concentrations would reduce total inorganic carbon in the water, elevate the pH, and increase the apparent saturation with respect to calcite.

Inorganic carbon lost to CO_2 exsolution is irretrievably lost. For the system under consideration, however, the magnitude of such loss is believed insignificant.

MINTEQA2 was used to determine the $P(CO_2)$ (and therefore that pH) at which the analyzed water would be in equilibrium with calcite. The model indicates that in-situ pH under the assumed consideration of equilibrium (rather than oversaturation) with calcite is 7.18 rather than the field-measured value of 7.53.

Geologic and petrographic data indicate a ubiquitous occurrence of disseminated pyrite. It is postulated that the in-situ water is in equilibrium with pyrite. MINTEQA2 was iteratively used to identify that eH and pH combination under which both calcite and pyrite would be in equilibrium with ground water.

Since silica was not among the analytes for the early samples, MINTEQA2 was used to estimate the probable H_4SiO_4 concentrations. Silica should be considered because some silicate minerals serve as pH buffers. Petrography and mineralogy suggest quartz saturation is probable. The program was used to identify the silica concentration at which the sampled water would be in equilibrium with the mineral quartz. The subsequent laboratory analyses for silica in the 1993 sample from borehole #778 confirmed the MINTEQA2-modeled estimate.

The mineral apatite is commonly noted in the area. Since phosphate concentrations in the whole water-analyses were below detection limits, MINTEQA2 was used to identify the phosphate concentration that would be in equilibrium with the mineral hydroxyapatite. The modeled equilibrium concentration is well below the detection

limit reported in the laboratory analysis and the non-detection of phosphate is, therefore, consistent with known country rock mineralogy. Model simulation results are shown in Table A-2. Table A-3 is a partial list of available minerals from the thermodynamic database with which the reference water is at, or nearly at, equilibrium. The saturation index for each mineral is given. Generally, a saturation index greater than zero indicates oversaturation with respect to that mineral and a saturation index of less than zero indicates undersaturation.

C-1.4 Verification of Model Results

The conceptual model is that ground water from the fractured volcanic bedrock is the principal source of mine drainage at the American Tunnel level. This conceptual model, and the modeled reference water characterization, can be tested against field and laboratory analyses to verify the validity of the assumptions. The laboratory analyses from mine drainage samples (Table A-1) are for water that has had the opportunity to partially equilibrate with the atmosphere and precipitate oversaturated minerals. These processes can be simulated with the program.

MINTEQA2 was used to identify the equilibrium state of the water under atmospheric conditions (i.e., $P(CO_2)$ = 0.00032 atm and $P(O_2)$ = 0.21 atm). Model-simulated equilibration of the water chemistry to the atmosphere (permitting precipitation to occur) produces the mineral assemblage and residual fluid chemistry shown in Table A-4. The total metals load has decreased significantly as insoluble metal oxides

precipitate. It is also noted that the pH has increased during precipitation. The pH increase reflects the combined effects of precipitation and fluid degassing. Note that the calcite precipitated (Table A-4) only partially balances the reduction in CO_3^- between the in-situ (Table A-2) and precipitated (Table A-4) cases. The balance is exsolved as CO_2 gas, thereby reducing hydrogen ion activity and raising pH. The laboratory values for pH from water from the mine workings (Tables A-1 and A-5) are a physical analog of this process and support model simulations.

Mine drainage samples from the shallower sections of the American Tunnel show pH declines rather than the increase identified in the previous MINTEQA2 run. This is the result of degassing prior to sample collection and the sequential precipitation of mineral assemblages as the solution equilibrates with the atmosphere, with no opportunity for the precipitated minerals to back react with the flowing water. This process can be simulated with MINTEQA2. The field pH of the reference water was 7.53 which, given the bicarbonate concentration, indicates oversaturation with atmospheric partial pressures of CO_2. The result of the $P(CO_2)$ decrease from formation conditions is an oversaturation with respect to calcite. If the water is permitted to degas and precipitate calcite at that point, and the remaining water is then oxidized to atmospheric $P(O_2)$, a lower pH (7.1) final solution is obtained and the final total metals load is higher. Table A-6 shows the precipitate totals and final water chemistry. Hence, the observed water chemistry in the American Tunnel drainage

ditch is in part due to the loss of some buffering capacity caused by mineral precipitation prior to complete equilibration to atmospheric conditions.

C-1.5 Impounded Water Chemistry

The water that will flood the mine when the American Tunnel bulkhead is installed is the reference water described above. Its chemical characterization is provided in Table A-2. Equilibration with atmospheric gas concentrations would be expected initially as reference water from the country rock fills the plugged mine. The process of sequential precipitation, as reference water fills the mine, may occur. If this occurs, it would be similar to that previously described for drainage along the tunnel floor with one important difference. Whereas the mine drainage leaves the precipitated minerals behind, minerals and fluid within the flooded mine would remain in contact and could potentially react with each other, maintaining much of the original buffering capacity of the water. To the extent that the reference water entering the mine workings oxidizes, it will regain some ability to dissolve ore minerals it contacts. The impact of this on water quality will be discussed later in this Appendix.

C-1.6 Potential Reactions Along Flow Paths

The saturation states of the American Tunnel reference water (the water that is expected to flood the deeper levels of the Sunnyside Mine) are reported in Table A-3. The results confirm that the sampled water is at equilibrium with the country rock.

In addition to the fixed equilibrium state with quartz, calcite, and pyrite, the water is at or near equilibrium with respect to muscovite (petrographically as sericite), kaolinite and other clays, fluorite, hematite, magnetite, and diaspore. Each of these is described in regional geologic literature and/or in the petrographic descriptions for samples from the American Tunnel. Further, among the feldspars in the MINTEQA2 data base, the water is near equilibrium only with low albite and microcline. This is again consistent with the known mineralogy of the propylitized country rock. Two minerals in the zeolite group are indicated as being oversaturated: laumontite and leonhardite. While neither is petrographically identified, both are likely plagioclase alteration products of the fine-grained volcanic ground mass. The non-detection of phosphate in the analysis is consistent with known apatite in the country rock.

In addition to equilibrium conditions existing between the country rock and the water, the calculation shows the reference water to be at equilibrium or oversaturated with rhodochrosite ($MnCO_3$), as well as each of the sulfide minerals which comprise the vein ores: pyrite (defined), sphalerite and galena. The dissolved cadmium concentrations could represent equilibrium with either or both greenockite (sulfide) or otavite (carbonate).

Equilibrium also exists with gypsum, a common sulfate mineral in the altered country rock and mineralized veins at deeper levels. The reference water is at or near equilibrium with the carbonates of cadmium, manganese, iron and zinc. As with flow

through the country rock mineral assemblage, the reference water would flow through ore bearing veins in the Sunnyside Mine area with virtually no reaction and no change in chemistry except possible precipitation. There would also be no tendency for this water to dissolve vein material, thereby enhancing migration. The equilibrium of this water in-situ with country rock and with vein mineralization is relevant so long as the oxidation state remains unchanged.

C-2 TERRY TUNNEL

C-2.1 Overview

The diversion of mine drainage from the Terry Tunnel into deeper levels of the mine workings and the installation of a bulkhead in the Terry Tunnel may impound water within the workings to elevations above the Terry Tunnel. Concerns regarding this proposed bulkhead include: 1) what is the character of the in-situ ground water, 2) what is the character of any impounded water, 3) what reactions may occur along flow paths, and 4) what is the eventual character of the water after it reaches the surface and equilibrates with atmospheric gas compositions.

C-2.2 Data

The chemical system associated the water produced from the Terry Tunnel is considerably less constrained than that for the American Tunnel. There are three whole water analyses that are from samples taken upstream of the discharge treatment facility at the Terry Tunnel portal. These are composite waters from the mine floor rather than water collected from any specific discharge point. There are no data at the Terry Tunnel level comparable to the drill hole data from the American Tunnel. Table A-7 contains the analyses of these three samples. No field data are available for these samples so neither sample-specific temperature nor field pH are available. There are a substantial number of records available, however, from samples

collected for metals testing (Simon Hydro-Search, 1992) that can be used for guidance.

The three analyses for Terry Tunnel water are from the period of 06/11/91 through 07/11/91. During this period, the flow volume ranged from 1.8 to 0.33 million gallons per day (Simon Hydro-Search, 1992, Figure 8). The flow variations represent, in part, a mixing of ground water with melt of the snow pack and with early summer rains that enter the system through open workings. A comparison of the chemical analyses with the discharge rates does not show a simple dilutional variation. Rather, there is systematic variation with time among various groups of constituents that may represent temporal variation of reactions or their rates, in combination with dilution effects. The precise nature or relative contributions of the different effects cannot be isolated with the limited data set. For purposes of modeling the Terry Tunnel water, the analysis that corresponds to the lowest discharge volume was selected as the best available characterization of the system. This sample was collected 07/11/91. It is felt that the lowest flow is temporally more representative of the shallower workings and it is conservative in that it represents the highest concentrations over the period sampled. In addition, the water selected had the lowest pH of the three.

Data omissions in the Terry Tunnel analyses impact the interpretation. Two of the three analyses report no carbonate or bicarbonate. There is also a substantial charge imbalance (13-14%) for these two analyses and that imbalance shows a relative

deficiency of anions. Water analyses from the American Tunnel levels of the Sunnyside mine show much better balance and show anion concentrations are in excess of cations. The latter is readily explained in that the cation contributions from the metals are not normally included in the ion balance calculation. An inclusion of the metals contribution in the Terry Tunnel water aggravates the imbalance. The single sample which does report inorganic carbon shows excellent charge balance (<1%).

An additional anomaly with respect to the Terry Tunnel analyses is that suspended solids range from 7 to 28 percent of the combined total of dissolved and suspended solids by the time laboratory analyses were run. This strongly suggests that considerable precipitate may have formed and that the water analyses in Table A-7 represent, to a significant degree, residual waters rather than the water that may be impounded by a bulkhead.

General water chemistry at the Terry Tunnel level is similar to American Tunnel water with some significant differences. Sulfate is again the dominant anion, but total concentrations are only a third to a quarter as high. Similarly, total dissolved solids are half or less. Inorganic carbon in the Terry Tunnel water is present in low concentrations or is under-reported. Calcium is the dominant cation, but is proportionally reduced with the sulfate concentration. Chloride and potassium levels are higher and strontium, fluoride, and sodium concentrations are comparable. Both

proportionately and absolutely, the Terry Tunnel waters show higher concentrations of magnesium, iron, manganese, zinc, lead and copper. Analytic results are shown in Table A-7.

Typical field-measured pH values from late summer periods of low flow are from 6 to 6.5. Laboratory-measured pHs have dropped to as low as 3.3 for the whole water samples and values from 3.5 to 4.5 are common for metals-only samples. The pH decrease is associated with a high proportion of suspended solids believed to be hydrated metal oxides.

C-2.3 Terry Tunnel Reference Water

Establishing a probable character of the in-situ vadose water or the impounded water behind the Terry Tunnel bulkhead is more problematic than at the American tunnel level. There are fewer analyses available and those that are available are less consistent and less reliable. Inferences made from the data are less certain, but some can still be drawn.

The analytic composition for the sample collected 07/11/91 was used in a MINTEQA2 simulation in which pH was determined by atmospheric equilibration with CO_2 and the redox state, by atmospheric concentrations of O_2. As with the American Tunnel system, sufficient silica was modeled to bring the system near equilibrium with quartz.

The Cu^{+}/Cu^{++} redox pair was added for the Terry Tunnel modeling to reflect the analytical presence of copper.

The simulation results for the water and an abbreviated list of computed saturation indices for minerals of interest are shown in Table A-8. It is noted that the calculated pH of the water, 3.7, is fairly consistent with the laboratory value of 3.3, but well below the typical field value of 6.4. At the assumed gas activities and silica concentrations, the analysis remains oversaturated with respect to clay minerals, oxides and hydroxides of iron, manganese and magnesium, and is at or near saturation with a number of sulfates, including gypsum. The simulation also predicts an inorganic carbon concentration of 0.8 mg/l as bicarbonate (speciated as H_2CO_3).

This simulation, and the local geology and petrography, suggest that the total absence of inorganic carbon is unlikely. Calcite is a common alteration mineral associated with the regional propylization and it is also a common vein mineral in the upper portions of the rock sequence. In addition, rhodochrosite is a common vein mineral. The charge imbalance and the absence of measured inorganic carbon anion species are probably related. It should be noted that at field pH values, inorganic carbon would occur dominantly as bicarbonate. However, at pHs reported in the laboratory analyses, the dominant carbon species would be H_2CO_3.

The mineralogy of the suspended solids was not determined. Differences between total and dissolved metal loads suggest iron compounds are a major contributor and there are lesser contributions from zinc, manganese, cadmium and lead. The concentrations of dissolved cadmium and lead, and to a lesser degree manganese and zinc, are consistent with common carbonate concentrations. This suggests that carbonate precipitation is controlling the dissolved concentration of these metals through early precipitation. If a representative concentration for CO_3 of $4x10^{-8}$ mg/l is used as a fixed constraint for MINTEQA2, the model predicts an inorganic carbon concentration of 6.4 mg/l as bicarbonate. This bicarbonate concentration is directly comparable to the one Terry Tunnel sample with detected inorganic carbon. Table A-9 shows the results of this simulation and lists the minerals that are at or near saturation. The computed pH for this system is 7.0. This value is slightly higher than, but consistent with, field pHs collected during comparable periods of low flow in late summer and early fall (Simon Hydro-Search, 1992, Appendix C). Further, although the added carbonate does not eliminate the charge balance problem, it does help reduce it. The modeled inorganic carbon concentration is believed to be a minimum likely value for vadose water entering the mine workings at the Terry Tunnel level and above.

The disparity between field and laboratory measurements for pH for the Terry Tunnel discharge waters and the strong precipitate formation are a clear indication that the water is not at equilibrium when sampled. That disequilibrium is largely a transient

condition as a flow of reduced vadose water equilibrates with atmospheric concentrations of oxygen. Terry Tunnel discharge water appears to be a mix of reduced vadose water and oxygenated surface water that enters the mine workings.

During periods of low flow, a high proportion of vadose water to surface water should exist. The water sample from 07/11/91, a low flow period, with restored inorganic carbon concentrations, was considered over an oxidation range from pE = 18 to pE = -3. This corresponds to the range from atmospheric concentrations of oxygen to a reduced state slightly lower than that modeled for the water from the American Tunnel level. When saturation indices for various minerals that could serve as sources for the analyzed total metals are plotted as a function of pE, it is observed that the minerals pyrite, galena, sphalerite and chalcopyrite are each in equilibrium with the analytic composition of the water at essentially the same oxidation state, about pE = -1.5. These minerals are the most abundant ore minerals for iron, lead, zinc and copper.

If the total concentration for each of these metals is the result of leaching as surface water runs along open faces of the mine workings in contact with minerals, it is a remarkable coincidence that the concentrations reflect common saturation at a single redox value. Alternatively, if the individual concentrations reflect an unsaturated flow composition that formed in common contact with all the minerals under a closed, reduced system, then the common pE at saturation would be expected. Of the two

scenarios, the latter is believed the more likely. The metals concentrations (total) indicate that mine discharge at the Terry Tunnel during periods of low flow is predominantly comprised of vadose water that acquired its observed metals load in a reduced environment through the dissolution to equilibrium of the most abundant sulfide ore minerals.

Terry Tunnel reference water is defined as the analytical water from 07/11/91 with a calculated inorganic carbon, sufficient silica to approach quartz saturation and a pE consistent with vadose water in equilibrium with the principal ore minerals. Table A-10 represents the output of a model simulation of this water and includes an abbreviated list of mineral saturation indices.

C-2.4 Impounded Water Chemistry

Water chemistry behind the Terry Tunnel bulkhead should closely resemble the Terry Tunnel reference water. This water will be subject to seasonal dilution and oxygenation as surface water flows into the workings. The magnitude of this impact, however, should be limited by two mechanisms. First, active efforts are underway to divert surface water away from entry points to the mine workings, so the historical seasonal fluctuations should diminish. Second, the dilute, oxygenated surface water will come in contact with the sulfides and carbonates in the flooded workings and move quickly toward a composition and redox state similar to the Terry Tunnel reference water. Consequently, the impounded water behind the proposed Terry

Tunnel bulkhead is expected to be similar to the Terry Tunnel reference water as described in Table A-10.

The modeling Terry Tunnel reference water used total metals concentrations where available, but does not contain the full metals load of the vadose water that sources it, nor does it contain anionic constituents that have precipitated from it. Based upon the apparent carbonate equilibrium among some of the metals and upon the calculations of sequential precipitation from the American Tunnel system, it is likely that the Terry Tunnel water that was analyzed had already lost part of its buffering capacity prior to analysis. Although there is no better available water to consider in building a reference water for the Terry Tunnel, it should be emphasized that using this water is conservative because this water is probably more reactive than the water that will collect behind the bulkhead.

C-2.5 Potential Reactions Along Flow Paths

An examination of the saturation states of the minerals from Table A-10 permits a qualitative statement of rock-water reactions that may occur between seepage around the proposed Terry Tunnel bulkhead and the country rock. As modeled, the Terry Tunnel reference water is undersaturated with respect to calcite, but is oversaturated with respect to a number of clay minerals. The Terry Tunnel reference water is at or near saturation with gypsum, other sulfates and several carbonates. Dissolution of calcite is expected to be more than off-set by precipitation of other pore-filling

materials. Aside from clay precipitation for example, common ion effects could readily cause gypsum to precipitate as calcite dissolves. The reference water for the Terry Tunnel is defined under relatively reduced conditions. To the extent that the impounded water may be seasonally diluted or partially oxygenated, it will retain some ability to dissolve certain ore minerals with which it comes in contact.

In the absence of surface drainage dilution, the impounded reference water is saturated with respect to sulfides in the vein systems. Migration along these paths toward the surface should not affect either the minerals or the water. Since the reference water is modeled as undersaturated with respect to rhodochrosite, some increase in dissolved manganese could occur. This would be accompanied by increased carbonate concentrations, a corresponding increase in buffering capacity, and a minor rise in pH.

C-3 MIXING OF WATERS

The discussions and modeling to this point have considered the American Tunnel and Terry Tunnel bulkheads as isolated systems. In spite of the efforts that will be undertaken to slow advective transport through the mine workings (by collapsing ore passes and shafts), mixing of the reference waters will probably occur. The final distribution and pattern of mixing cannot be predicted. However, some observations can be made and qualitative calculations performed.

Each reference water can be considered an end member, generally representative of the deepest and shallowest portions of the flooded workings. As with the reference waters, the shallower waters are likely to be the most diluted, least reduced and contain the highest metals concentrations. The deeper waters will represent more reduced conditions, have higher total dissolved mass, and have lower metals concentrations. Each reference water is essentially in equilibrium with the minerals of the migration path to the surface, so the nature of the mass transfer to the surface is largely a question of the relative amounts of each end member in the final mix. For purposes of considering the impacts of surface discharge, two mix ratios are considered: 4:1 and 1:1 (American Tunnel reference water to Terry Tunnel reference water).

The MINTEQA2 program cannot perform an equilibrium calculation that includes a redox prediction for a compositional mix of two redox waters. However, it is reasonable to assume that the oxidation state of the mix of two waters will lie within the range of the end members. Table A-11 shows the result of the 4:1 compositional mix before and after precipitation within the mine workings. The pE of the system was chosen as -2.2, which is proportionally closer to the American Tunnel water chemistry. Table A-12 shows the result of 1:1 composition mix and a pE of -1.8, intermediate between the two end members.

Although each end member is at saturation with the minerals associated with the mine workings and vein minerals, either mix is oversaturated with respect to a number of these and other minerals. In the model, if these minerals precipitate within the workings or along the migration path, both the concentration and total load of the metals delivered to the surface is reduced. Virtually all iron and manganese may precipitate. In the case of zinc, up to 73% can potentially be precipitated before the water reaches discharge at the surface. The precipitation of minerals from the mixing of two equilibrium solutions is one of the processes by which supergene enrichment can occur in sulfide mineral deposits, a physical analog of this calculation.

The program requires an assigned redox state in order to perform the calculation. Hence, the amount of precipitation is a function of the assigned redox state. For this reason, the modeling of surface discharge will be considered with the full metals load,

not reduced by any precipitation within the workings or along the flow path. This is a conservative assumption, which will result in an estimate of metals load that may be somewhat high.

C-4 SURFACE WATER DISCHARGE

Eventually the waters backed up behind both the proposed American Tunnel bulkhead and the proposed Terry Tunnel bulkhead will reach the ground surface as seeps or springs issuing from natural fractures in the volcanic rocks. The result of that discharge will be the oxidation of dissolved metals and the precipitation of any over-saturated minerals. This process will result in less impact to streams than that of tunnel drainage because of the disseminated, distributed nature of the process. Since the water will be moving through porous media, it will move at a slower rate (and at a lower volume) than open flow through the mine system. It will also have the benefit of a larger surface area of gas exchange. This will result in water that equilibrates with the atmosphere while in contact with any early precipitates, permitting back reaction and full benefit of any buffering capacity of the system.

Table A-4 characterizes discharge water that would result from precipitation of the American Tunnel reference water in equilibrium with the atmosphere. Table A-13 shows the expected final water chemistry of the Terry Tunnel reference water, as well as the simulated precipitation after equilibration with the atmosphere. Table A-11 presents the composition of a 4:1 mix of American Tunnel water to Terry Tunnel water. This ratio is approximately representative of the present relative discharge of the two systems, excluding the spring run-off period of the Terry Tunnel.

Table A-12 is the 1:1 mix of the two reference waters discussed above. Tables A-14 and A-15 show the mixed waters after equilibration with the atmosphere and precipitation of all oversaturated minerals. It is important to remember that the simulations were based on the assumption that none of the metals load was precipitated enroute to the surface discharge.

The final waters are dilute of significant metals concentrations, have relatively low total dissolved solids and are relatively neutral with respect to pH. The modeled precipitates are those which are expected in settings like the iron "bogs" that naturally occur in the area. These bogs almost certainly represent the analogous system operating in nature.

C-5 MIXING WITH SURFACE WATER

The final step in the modeling is to consider the impact of the discharging ground water, after reaching equilibrium, on the chemistry of Cement Creek. For this effort, it was assumed that the most likely volume of discharging ground water subject to possible passage through the mine was 75 gpm. Evapotranspiration losses were not considered. The modeled chemistries of discharging waters are shown in Tables A-14 and A-15. The chemical characterizations shown in Table A-16 represent the water in Cement Creek above the mine during the two periods of highest and lowest flow from which samples were taken between 04/09/87 and 04/23/91 (Simon Hydro-Search, 1992, Appendix C). Also included in Table A-16 are the results of the modeled discharge waters after equilibrium with the atmosphere and precipitation of their minerals. The modeled discharge chemistry will have no deleterious effects on Cement Creek water during periods of either high or low flow. In all cases, the carbonate content in the discharged mix will tend to neutralize the acid character of the stream, raising the pH of the stream. The concentrations of metals are comparable among low flow, high flow and modeled waters. The natural waters carry somewhat more iron and manganese and somewhat less zinc, with the contrast greater at periods of high flow. The iron and manganese concentrations are probably attributable to some combination of the lower pH in the stream, disequilibrium due to the kinetics of oxide precipitation, and/or poorly filtered suspended load from the stream waters.

Table A–1. Water analyses from deeper portions of the American Tunnel

Source	Date	Location	Flow MGD	Field pH	Field Conduct	Field Temp deg–C	Lab pH	Lab Conduct	TDS	TSS
west–drift	03/05/91	floor					6.71	1740	1670	56
Wash–fw	03/05/91	floor					7.24	1850	1700	1
Wash–hw	03/05/91	floor					7.54	1850	1710	<1
Wash–hw	03/13/91	floor					7.17	1990	1650	2
2195–op	03/05/91	floor					2.86	63200	7710	8
SS–drift	03/05/91	floor					7.60	1340	1140	1
SS–drift	03/13/91	floor					7.18	1430	1130	1
SS–xcut	01/04/93	spring					6.80	2070	1880	7
AT–7350	07/23/92	ditch	0.93	6.45	1850	14	6.50	1770	1610	38
DH–781	10/07/91	pipe		7.32	1140	13	7.06	1540	1360	6
DH–778	10/07/91	pipe		7.54	1200	12.8	6.39	1610	1420	63
DH–778	01/04/93	pipe					7.50	1810	1600	4
AT–6400	07/23/92	ditch	1.30	6.68	1880	13.3	6.69	1750	1650	36
AT–6400	01/31/92	ditch	1.34	7.93	1740	13.7	7.01	1970	1670	14

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Table A–1. Water analyses from deeper portions of the American Tunnel, Con't.

Location	Major Anions				Major Cations						
	Sulfate	Bicarb	Fluoride	Chloride	Ca	Na	Mg	Sr	Al	K	Si
West–drift	1150	62.8	7.08	4.08	434	5.9	38.2	4.68	0.5	0.81	
Wash–fw	1130	163.0	4.19	4.08	430	6.2	47.7	3.99	0.2	1.44	
Wash–hw	1220	79.3	2.47	4.08	310	14.8	121.0	7.54	<.1	1.17	
Wash–hw	1230	73.2	2.27	2.04	174	15.0	198.0	7.29	<.1	1.11	
2195–op	5550	0.0	2.47	9.19	1860	9.8	285.0	3.62	101	2.09	
SS–drift	769	100.0	2.39	3.06	267	12.9	40.4	6.03	<.1	1.13	
SS–drift	766	98.2	1.79	1.02	252	11.9	52.1	5.78	<.1	1.05	
SS–xcut	1290	94.0	1.95	1.30	430	40.0	65.0	12.80	0.3	1.30	8.9
AT–7350	1200	31.7	4.82	0.51	363	8.8	18.1	6.79	1.3	0.50	
DH–781	905	102.0	1.33	<0.1	390	4.6	6.2	4.99	0.8	<.1	
DH–778	925	153.0	2.97	<0.1	414	3.0	4.0	3.78	0.6	<.1	
DH–778	1100	104.0	0.92	1.30	400	6.3	44.0	13.70	0.1	0.40	>3.7
AT–6400	1210	54.3	4.08	3.60	379	7.6	15.1	7.09	1.5	0.39	
AT–6400	1110	92.1	2.87	1.64	495	7.3	6.0	9.28		0.64	

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Table A–1. Water analyses from deeper portions of the American Tunnel, Con't.

Location	Metals Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)
West–drift	5.47	15.50	17.70	18.65	17.90	16.70	<.005	0.24	0.082	0.106
Wash–fw	<.05	0.38	61.90	64.29	34.30	33.43	<.005	0.21	0.073	0.090
Wash–hw	0.07	0.17	2.01	1.58	0.75	0.59	<.005	0.19	0.005	0.005
Wash–hw	0.06	0.22	2.21	2.18	0.98	0.95	<.005	0.15	<.002	0.002
2195–op	192.00		946.00		701.00		1.53		2.065	
SS–drift	0.14	0.25	2.10	1.83	0.09	0.09	<.005	0.18	0.003	0.000
SS–drift	<.05	0.18	1.87	1.94	0.06	0.07	<.005	0.08	<.002	0.004
SS–xcut	2.56	2.68	15.10	15.30	5.38	5.36	<.005	<.005	<.002	0.002
AT–7350	1.99		35.20		29.00		0.06		0.123	
DH–781	<.05		1.17		0.05		0.02		<.002	
DH–778	1.59		6.91		4.25		<.02		0.030	
DH–778	<.05	0.13	1.21	1.25	<.01	<.01	<.005	<.005	<.002	<.002
AT–6400	4.87		25.70		21.20		0.05		0.076	
AT–6400	0.17	6.62	11.2	11.33	7.84	7.8	0.04	0.12	0.030	0.047

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Table A–1. Water analyses from deeper portions of the American Tunnel, Con't.

Location	Metals (con't) Copper (Diss)	Copper (Total)	Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
West–drift	<.01	0.21	<.001		<.005	<.05	<.02	<.05	<.005	<.01
Wash–fw	<.01	0.13	<.001		<.005	0.060	<.02	<.05	<.005	<.01
Wash–hw	<.01	0.03	<.001		<.005	0.060	<.02	<.05	<.005	<.01
Wash–hw	<.01	0.02	<.001		<.005	0.050	<.02	<.05	<.005	<.01
2195–op	24.80		<.001		0.036	<.01	<.02	<.05	<.005	<.01
SS–drift	<.01	0.02	<.001		<.005	0.060	<.02	<.05	<.005	<.01
SS–drift	<.01	<.01	<.001		<.005	0.030	<.02	<.05	<.005	<.01
SS–xcut	0.01	0.01	<.001	<.001	0.005		<.02	0.030	<.005	0.020
AT–7350	0.66		<.001		0.005	0.060	0.170	<.05	<.005	<.01
DH–781	<.01		<.001		<.005	<.01	<.02	<.05	<.005	<.01
DH–778	<.01		<.001		<.005	<.01	<.02	0.060	<.005	<.01
DH–778	0.01	0.01	<.001	<.001	<.005		<.02	0.005	<.005	0.030
AT–6400	0.79		<.001		0.007	0.090	0.150	<.05	<.005	<.01
AT–6400	<.01	0.13	<.002	<.002	<.005	<.01	<.02	0.120	<.005	0.040

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Table A–2. American Tunnel reference water

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	925	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	150	analysis	CO_3^{--}	HCO_3^-
Chloride	0.05	1/2 detect lim	Cl^-	Cl^-
Fluoride	2.97	analysis	F^-	F^-
Phosphate	0.007	mineral equil	PO_4^{---}	HPO_4^{--}
Calcium	414	analysis	Ca^{++}	Ca^{++}
Magnesium	4.03	analysis	Mg^{++}	Mg^{++}
Sodium	2.99	analysis	Na^+	Na^+
Aluminum	0.6	analysis	Al^{+++}	$Al(OH)_3$ aq
Potassium	0.05	1/2 detect lim	K^+	K^+
Silica	5.93	mineral equil	H_4SiO_4	H_4SiO_4
Iron	2.75	comb. analysis	Fe^{++}/Fe^{+++}	Fe^{++}
Manganese	8.08	comb. analysis	Mn^{++}/Mn^{+++}	Mn^{++}
Zinc	5	comb. analysis	Zn^{++}	Zn^{++}
Strontium	3.78	analysis	Sr^{++}	Sr^{++}
Cadmium	0.04	comb. analysis	Cd^{++}	Cd^{++}
Lead	0.025	comb. analysis	Pb^{++}	$PbCO_3$ aq
pH	7.18	mineral equil	H^+	HCO_3^-
pE	−2.46	mineral equil	e^-	MnO_4^{--}

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Table A–3. Saturation indices of selected minerals with respect to American Tunnel reference water

Mineral	Saturation Index	Type	
Greenockite	4.86	cadmium sulfide	
Galena	2.87	lead sulfide	
Sphalerite	2.65	zinc sulfide	
Pyrite	0.00	iron sulfide	
MnS green	−12.84	*manganese sulfide*	
Diaspore	3.48	aluminum oxide/hydroxide	
Boehmite	1.67	aluminum oxide/hydroxide	
Gibbsite	1.65	aluminum oxide/hydroxide	
Goethite	0.06	iron oxide/hydroxide	
$Al(OH)_3$	−0.10	aluminum oxide/hydroxide	
Magnetite	6.36	iron oxide (multiple)	
Hematite	5.08	iron oxide (multiple)	
Al_2O_3	−0.69	aluminum oxide (multiple)	
Fluorite	0.82	calcium fluoride	
Otavite	0.73	cadmium carbonate	
Rhodochrosite	0.10	manganese carbonate	
Calcite	0.00	calcium carbonate	
Siderite	−0.33	iron carbonate	
Smithsonite	−0.77	zinc carbonate	
Cerussite	−1.00	lead carbonate	
Strontianite	−1.44	strontium carbonate	
Dolomite	−1.88	Ca++/Mg++carbonate	
Alunite	2.52	potasium sulfate	
Gypsum	0.01	calcium sulfate	
Anhydrite	−0.33	calcium sulfate	
Celestite	−0.65	strontium sulfate	
Anglesite	−2.85	lead sulfate	
Fluorapatite	10.85	F−/Ca++ phosphate	
Hydroxyapatite	0.00	OH−/Ca++ phosphate	
Leonhardite	15.62	frame silicate	(zeolite)
Laumontite	1.34	frame silicate	(zeolite)
Quartz	0.00	frame silicate	
Microcline	−1.28	frame silicate	(feldspar)
Albite (low)	−1.41	frame silicate	(feldspar)
Nontronites	13.16	sheet silicate	(clay)
(Ca, Mg, Na, K)	5.86	sheet silicate	(clay)
Kaolinite	7.02	sheet silicate	(clay)
Montmorillonite	5.50	sheet silicate	(clay)
Muscovite	7.13	sheet silicate	(mica)
Pyrophyllite	7.07	sheet silicate	(mica)

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TABLE A–4

AMERICAN TUNNEL REFERENCE WATER
After Equilibration to Atmosphere and Precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	9.644E-03	926	SO_4--
CO_3--	5.66E-04	33.9	HCO_3-
Cl-	1.412E-06	0.05	Cl-
F-	5.856E-05	1.11	F-
Ca++	8.396E-03	337	Ca++
Mg++	1.660E-04	4.04	Mg++
Na+	1.303E-04	3.00	Na+
Al+++	6.181E-09	ND	$Al(OH)_3$ aq
K+	1.281E-06	0.05	K+
H_4SiO_4	1.238E-07	ND	H_4SiO_4
Fe+++	2.486E-15	ND	$Fe(OH)_2$+
Mn++	2.619E-16	ND	Mn++
Zn++	1.493E-05	0.97	Zn++
Sr++	4.321E-05	3.79	Sr++
Cd++	5.344E-08	0.006	Cd++
Pb++	1.208E-07	0.025	$PbCO_3$ aq
pH	7.87		
pE	13.81		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Calcite	1.91E-03	191.171	Gypsum	-0.04
Pyrolusite	1.47E-04	12.780	Anhydrite	-0.38
$ZnSiO_3$	6.17E-05	8.728	Celestite	-0.60
Fluorite	4.90E-05	3.826	Cerussite	-0.99
Hematite	2.47E-05	3.944	Strontianite	-1.33
Diaspore	2.23E-05	1.338	Smithsonite	-1.39
Otavite	3.03E-07	0.052		

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Table A–5. Water analyses from shallower portions of the American Tunnel

Location	Date	Source	Flow MGD	Field pH	Field Conduct	Field Temp deg–C	Lab pH	Lab Conduct	TDS	TSS
AT–3450	07/23/92	ditch	1.41	6.67	1900	12.9	6.36	1830	1660	48
Fault–1	03/05/91	seep		5.90			2.45	3030	2560	42
Fault–2	03/05/91	seep		6.05			2.49	3440	2890	46
AT–2700	07/23/92	ditch	1.90	6.43	1980	12.1	4.77	1820	1730	88
AT–2400	07/23/92	ditch	2.06	6.36	1990	12.1	4.7	1860	1740	90
AT–portal	07/23/92	flume	2.20	6.36	1930	11.7	5.18	1880	1720	84
AT–portal	01/31/92	flume	3.17	6.60	1780	11.5	5.78	1920	1750	67

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

					Na	Mg	Sr	Al	K	Si
				379.0	7.6	163	6.68	0.5	1.40	
			0.50	42.5	13.6	161.0	5.59	12.8	1.50	
			6.13	13.9	9.2	21.7	5.89	22.3	1.69	
		6.46	<.10	380.0	7.4	16.3	6.73	1.9	0.39	
	2.44	6.46	0.82	391.0	7.4	19.3	6.46	1.9	1.17	
	1300	7.93	5.94	1.03	385.0	7.8	19.3	6.49	1.8	0.39
Al–portal	1230	15.90	5.04	1.75	496.0	7.0	12.7	8.48	0.9	

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

Location	Metals									
	Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)
AT–3450	0.3		26.0		21.2		<.01		0.08	
Fault–1	360.0	344.0	101.0	91.4	62.4	47.08	<.005	0.21	0.03	0.06
Fault–2	537.0	531.0	151.0	132.6	92.1	70.1	0.43	0.59	0.09	0.11
AT–2700	15.0		28.8		20.9		<.01		0.07	
AT–2400	5.6		30.5		20.3		<.01		0.06	
AT–portal	10.5	36.2	25.7	29.2	18.7	20.6	<.01	0.05	0.07	0.07
AT–portal		39.7	16.1	18.6	8.1	10.3	0.03	0.05	0.02	0.03

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

Location	Metals (con't.) Copper (Diss)	Copper (Total)	Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
AT–3450	0.18		<.001		<.005	0.12	0.13	<.05	0.005	<.01
Fault–1	<.01	0.34	<.001		<.005	<.01	<.02	<.05	<.005	<.01
Fault–2	<.01	0.03	<.001		<.005	<.01	<.02	<.05	<.005	<.01
AT–2700	0.33		<.001		<.005	0.13	0.16	<.05	<.005	<.01
AT–2400	0.29		<.001		<.005	0.16	0.14	<.05	<.005	<.01
AT–portal	0.23	0.82	<.001	<.001	<.005	0.15	0.17	<.05	<.005	<.01
AT–portal	0.04	0.07	<.002	<.002	<.005	<.01	<.02	0.12	<.005	<.01

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TABLE A–6

AMERICAN TUNNEL REFERENCE WATER

CO_2 flashed, calcite precipitated, then equilibrated with the atmosphere and again precipitated

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4––	9.644E–03	926	SO_4––
CO_3––	1.042E–04	6.25	HCO_3–
Cl–	1.412E–06	0.05	Cl–
F–	5.539E–05	1.05	F–
Ca++	9.445E–03	379	Ca++
Mg++	1.660E–04	4.04	Mg++
Na+	1.303E–04	3.00	Na+
Al+++	5.480E–09	ND	$Al(OH)_3$ aq
K+	1.281E–06	0.05	K+
H_4SiO_4	8.160E–07	ND	H_4SiO_4
Fe+++	7.112E–15	ND	$Fe(OH)_2$+
Mn++	9.213E–15	ND	Mn++
Zn++	7.085E–05	4.63	Zn++
Sr++	4.321E–05	3.79	Sr++
Cd++	3.564E–07	0.04	Cd++
Pb++	1.208E–07	0.025	$PbSO_4$ aq
pH	7.09		
pE	14.56		

Precipitated Minerals:	moles	mg	Minerals near saturation:	S.I.
Calcite *	8.515E–04	85.23	Gypsum	–0.01
Pyrolusite	1.473E–04	12.81	Anhydrite	–0.34
Ca–Nontronite	1.581E–05	6.71	Mg–Nontronite	–0.59
Fluorite	5.061E–05	3.95	Celestite	–0.62
Hematite	8.845E–06	1.41	Calcite	–1.50
Diaspore	1.888E–05	1.13	Otavite	–0.68
$ZnSiO_3$	2.934E–06	0.42	Cerussite	–1.81
			Smithsonite	–2.21
			Strontianite	–2.89

* precipitated in earlier step

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Table A–7. Water analyses from the Terry Tunnel

Location	Date	Source	Flow MGD	Field pH	Field Conduct	Field Temp deg–C	Lab pH	Lab Conduct	TDS	TSS
Influent	06/11/91	ditch	1.30	5.60		10.0	5.33	528	359	92
Influent	06/17/91	ditch	1.80	4.40		9.9	4.2	587	426	166
Influent	07/11/91	ditch	0.33	4.10			3.32	933	726	54

Location	Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Sr	Al	K	Si
Influent	264	3.05	2.37	1.42	55.7	1.5	33.9	0.56	0.9	1.14	
Influent	300	0.00	3.38	5.31	117.0	2.2	0.1	0.61	1.5	1.73	
Influent	544	0.00	5.56	0.30	160.0	1.7	19.0	0.98	3.2	1.20	

Location	Metals Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)	Copper (Diss)	Copper (Total)
Influent	0.1		29.1		20.1	20.41	0.06	1.00	0.09	0.06	1.43	1.83
Influent	0.7		37.4		25.3		0.06		0.02		2.77	
Influent	4.1	13.2	76.8	77.8	47.3	47.6	0.88	1.05	0.19	0.19	5.05	5.11

Location	Metals (con't.) Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
Influent	<.0002	<.0002	<.002	<.05	<.02	<.05	<.002	<.01
Influent	<.0002		<.002	<.01	<.02	<.05	<.002	<.01
Influent	<.0002	<.0002	0.008	0.08	<.02	<.05	<.002	<.01

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able A–8. Terry Tunnel water equilibrated to atmospheric gas concentrations (This table gives the results of MINTEQA2 modeling.)

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	7.9	atmos equil	CO_3^{--}	H_2CO_3 aq
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF^{++}
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	$Fe(OH)_2^+$
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^{++}
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	Pb^{++}
pH	3.70	atmos equil	H^+	
pE	18.58	atmos equil	e^-	MnO_4^-

Mineral saturation indices			
Sates:		Fluorite	−1.39
itronites	18.28 to 10.97		
tz	0.06	Oxides/hydroxides:	
		Hematite	13.22
		Pyrolusite	4.69
	−0.48	Goethite	4.15
	−0.50	Magnetite	1.12
	−0.89	Manganite	−0.04
	−1.36	Diaspore	−3.55

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Table A–9. Terry Tunnel water with restored inorganic carbon equilibrated to atmosphere
(This table gives the results of MINTEQA2 modeling.)

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	6.41	mineral equil	CO_3^{--}	HCO_3^-
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF_3 aq
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	$Fe(OH)_2^+$
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^{++}
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	$PbSO_4$ aq
pH	7.01	atmos equil		
pE	15.27	atmos equil		MnO_4^-

Mineral saturation indices

Silicates:		Oxides/hydroxides:	
Nontronites	28.89 to 21.58	Hematite	20.36
Leonhardite	14.77	Magnetite	11.83
Muscovite	8.96	Pyrolusite	11.30
Montmorillonite	8.29	Goethite	7.72
Pyrophyllite	8.08	Manganite	6.57
Kaolinite	7.50	Diaspore	3.65
Microcline	0.18	Tenorite	0.87
Quartz	0.06		
		Carbonates:	
Sulfates:		Malachite	1.23
Brochantite	5.06	Otavite	−0.11
Gypsum	−0.47	Cerussite	−0.17
Anglesite	−0.58	Rhodochrosite	−0.53
Anhydrite	−0.89	Smithsonite	−1.38
Celestite	−1.35	Calcite	−2.00
Fluorite	−0.17		

Table A–10. Terry Tunnel reference water

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	6.41	mineral equil	CO_3^{--}	HCO_3^-
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF_3 aq
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	Fe^{++}
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^+
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	Pb^{++}
pH	7.01	atmos equil	H^+	HCO_3^-
pE	–1.50	mineral equil	e^-	MnO_4^-

Mineral saturation indices

Silicates:		Oxides/hydroxides:	
Nontronites	15.11 to 7.80	Magnetite	7.93
Leonhardite	14.77	Cuprite	7.56
Muscovite	8.96	Hematite	6.58
Pyrophyllite	8.08	Diaspore	3.65
Montmorillonite	6.78	Gibbsite	1.84
Kaolinite	7.51	Goethite	0.83
Microcline	0.18		
Quartz	0.06		
		Carbonates:	
Sulfates:		Otavite	–0.11
Gypsum	–0.48	Cerussite	–0.17
Anglesite	–0.58	Rhodochrosite	–0.53
Anhydrite	–0.89	Smithsonite	–1.38
Celestite	–1.35	Calcite	–2.00
Fluorite	0.51	Sulfides:	
		Chalcocite	18.78
		Chalcopyrite	4.83
		Greenockite	0.60
Metallic Copper	6.96	Galena	0.24
		Sphalerite	–1.45
		Pyrite	–7.87

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Table A–11.
1:4 Mix of Terry and American Tunnels Water
Water mix with and without precipitation in flooded mine
(This table gives the results of MINTEQA2 modeling.)

	Mixed Waters no precipitation mg/L	*Mixed Waters precipitated mg/L*	*Relative Amount precipitated %*
SO_4--	850	841	1.1
HCO_3-	123	106	13.4
Cl-	0.10	0.10	0.0
F-	3.49	1.00	71.4
Ca++	364	361	0.7
Mg++	7.0	7.0	0.0
Al+++	1.12	ND	100.0
Na+	2.74	2.74	0.0
K+	0.28	0.28	0.0
H_4SiO	5.81	0.06	99.0
Mn	22.0	7.07	67.8
Zn++	13.5	3.63	73.1
Fe	4.58	ND	99.9
Cu	1.02	ND	100.0
Sr++	3.22	3.22	0.0
Pb++	0.23	0.01	96.3
Cd++	0.07	ND	99.8
pH	7.06	7.32	
pE	−2.2	−2.2	

Minerals Precipitated:	*moles precipitated per liter of solution*	*mg precipitated per liter of solution*
Rhodochrosite	2.72E−04	31.3
Sphalerite	9.15E−05	8.9
$ZnSiO_3$	5.99E−05	8.5
Hematite	3.64E−05	5.9
Fluorite	6.60E−05	5.2
Diaspore	4.16E−05	2.5
Cuprous ferrite	9.15E−06	1.5
Chalcocite	3.47E−06	0.6
Galena	1.07E−06	0.3
Greenockite	6.22E−07	0.1

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Table A–12.
1:1 Mix of Terry and American Tunnels Water
Water mix with and without precipitation in flooded mine
(This table gives the result of MINTEQA2 modeling.)

	Mixed Waters no precipitation mg/L	*Mixed Waters precipitated mg/L*	*Relative Amount precipitated %*
SO_4--	735	723	1.6
HCO_3-	79.5	61.2	23.0
Cl-	0.18	0.18	0.0
F-	4.27	1.09	74.5
Ca++	287	284	1.2
Mg++	11.5	11.5	0.0
Al+++	1.90	ND	100.0
Na+	2.35	2.35	0.0
K+	0.63	0.63	0.0
H_4SiO	5.62	0.05	99.0
Mn	43.0	26.5	38.4
Zn++	26.3	14.9	43.3
Fe	7.83	0.01	99.9
Cu	2.55	ND	100.0
Sr++	2.38	2.38	0.0
Pb++	0.54	0.02	97.1
Cd++	0.12	ND	99.5
pH	6.98	7.00	
pE	−1.8	−1.8	

Minerals Precipitated:	*moles precipitated per liter of solution*	*mg precipitated per liter of solution*
Rhodochrosite	3.00E−04	34.4
Sphalerite	1.17E−04	11.3
$ZnSiO_3$	5.79E−05	8.2
Hematite	5.00E−05	8.0
Fluorite	8.39E−05	6.6
Cuprous ferrite	4.02E−05	6.1
Diaspore	7.05E−05	4.2
Galena	2.52E−06	0.6
Greenockite	1.02E−06	0.1

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Table A–13.
Terry Tunnel reference water after equilibration to atmosphere and precipitation
(THESE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	5.668E–03	544	SO_4--
CO_3--	1.288E–05	0.77	H_2CO_3 aq
Cl–	8.469E–06	0.30	Cl–
F–	2.929E–04	5.56	AlF_3 aq
Ca++	3.993E–03	160	Ca++
Mg++	7.821E–04	19.0	Mg++
Na+	7.401E–05	1.70	Na+
Al+++	1.142E–04	3.08	AlF_3 aq
K+	3.072E–05	1.20	K+
H_4SiO_4	6.028E–06	ND	H_4SiO_4
Fe+++	5.626E–08	ND	FeF++
Mn++	4.448E–06	ND	Mn++
Cu++	8.040E–05	5.11	Cu++
Zn++	7.288E–04	47.6	Zn++
Sr++	1.119E–05	0.98	Sr++
Cd++	1.692E–06	0.19	Cd++
Pb++	5.072E–06	1.05	Pb++
pH	2.60		
pE	19.68		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	1.41E–03	122.93	Mg–Nontronite	–0.42
Hematite	1.05E–04	16.78	Gypsum	–0.48
Ca–Nontronite	1.34E–05	5.72	Anglesite	–0.50
			Anhydrite	–0.89
			Quartz	–0.90
			Fluorite	–1.11
			Celestite	–1.36

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Table A–14.
4:1 Mix (American Tunnel to Terry Tunnel) of reference waters after equilibration to atmosphere and precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	8.849E–03	850	SO_4--
CO_3–	5.566E–04	33.4	HCO_3–
Cl–	2.823E–06	0.10	Cl–
F–	5.238E–05	1.00	F–
Ca++	9.013E–03	361	Ca++
Mg++	2.892E–04	7.03	Mg++
Na+	1.190E–04	2.74	Na+
Al+++	8.842E–09	ND	$Al(OH)_3$ aq
K+	7.169E–06	0.28	K+
H_4SiO_4	2.387E–08	ND	H_4SiO_4
Fe+++	3.561E–15	ND	$Fe(OH)_2$+
Mn++	2.464E–16	ND	Mn++
Cu++	4.063E–06	0.26	$Cu(OH)_2$ aq
Zn++	1.373E–04	8.98	Zn++
Sr++	3.681E–05	3.23	Sr++
Cd++	6.526E–08	0.01	Cd++
Pb++	8.555E–07	0.18	$PbCO_3$ aq
pH	7.82		
pE	14.18		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	4.01E–04	34.88	Gypsum	–0.04
$ZnSiO_3$	6.04E–05	8.55	Calcite	–0.07
Hematite	4.10E–05	6.55	Cerussite	–0.11
Fluorite	6.60E–05	5.15	Brochantite	–0.42
Tenorite	1.20E–05	5.10	Anhydrite	–0.42
ZnO (Active)	9.37E–06	4.24	Smithsonite	–0.55
Diaspore	4.16E–05	2.49	Malachite	–0.64
Otavite	5.58E–07	0.10	Celestite	–0.72
Plattnerite	2.55E–07	0.06		

Table A–15.
1:1 Mix of American Tunnel and Terry Tunnel reference waters after equilibration to atmosphere and precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4– –	7.647E–03	735	SO_4– –
CO_3– –	2.320E–04	13.9	HCO_3–
Cl–	4.941E–06	0.18	Cl–
F–	5.713E–05	1.09	F–
Ca++	7.089E–03	284	Ca++
Mg++	4.741E–04	11.5	Mg++
Na+	1.022E–04	2.35	Na+
Al+++	8.521E–09	ND	$Al(OH)_3$ aq
K+	1.600E–05	0.63	K+
H_4SiO_4	5.025E–08	ND	H_4SiO_4
Fe+++	5.423E–15	ND	$Fe(OH)_2$+
Mn++	1.410E–15	ND	Mn++
Cu++	3.832E–06	0.24	$Cu(OH)_2$ aq
Zn++	3.443E–04	22.5	Zn++
Sr++	2.720E–05	2.38	Sr++
Cd++	3.485E–07	0.04	Cd++
Pb++	2.147E–06	0.44	$PbCO_3$ aq
pH	7.43		
pE	14.57		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	7.82E–04	68.00	Tenorite	–0.08
Hematite	7.01E–05	11.20	Gypsum	–0.16
$ZnSiO_3$	5.84E–05	8.27	Anhydrite	–0.54
Fluorite	8.40E–05	6.56	Malachite	–0.80
Diaspore	7.05E–05	4.23	Celestite	–0.87
Brochantite	9.09E–06	3.86	Smithsonite	–0.87
Otavite	6.76E–07	0.12	Calcite	–0.94
Cerussite	4.49E–07	0.12		

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Table A–16. Comparison of modeled *discharge water* with chemistry of Cement Creek

Date	Source	Flow MGD	Field pH	Field Temp deg–C	Lab pH	Major Anions Sulfate	Bicarb	Fluoride	Chloride
05/31/89	Cement Creek	15.67	3.9	12.0	4.1	50		4.8	
07/02/87	Cement Creek	11.47	3.9	8.8	4.2	60	0.0	0.4	0.0
	4:1 Spring Wtr	0.11	7.8	9.0		850	33.4	1.0	0.1
	1:1 Spring Wtr	0.11	7.4	9.0		735	13.9	1.1	0.2
03/29/91	Cement Creek	0.32	4.2	5.0	4.5	462	0.0	2.2	3.1
02/11/91	Cement Creek	0.23	5.7	1.9	3.5	439	0.0	3.1	2.0

Date	Source	Major Cations Ca	Na	Mg	Al	K	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
05/31/89	Cement Creek	17	8.4	0.2	1.8	0.9	1.2	0.5	1.4	0.24	0.04	0.01
07/02/87	Cement Creek	16	1.0	4.0	0.8	0.0	0.7	1.0	3.8	0.13	ND	0.03
	4:1 Spring Wtr	361	2.7	7.0	0.0	0.3	0.0	0.0	9.0	0.26	0.18	0.01
	1:1 Spring Wtr	284	2.4	11.5	0.0	0.6	0.0	0.0	22.5	0.24	0.44	0.04
03/29/91	Cement Creek	147	2.3	14.1	5.2	0.6	0.3	6.8	6.0	0.26	0.25	0.02
02/11/91	Cement Creek	135	4.1	15.2	6.7	0.7	1.1	8.3	7.4	0.40	0.29	0.07

Cement Creek water quality after bulkhead installation:		Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Al	K
High flow and 4:1 mix	13.68	61	0.3	2.9	0.0	19	5.3	1.8	1.4	0.5
Low flow and 4:1 mix	0.385	566	9.5	2.1	1.9	205	3.0	12.4	4.2	0.5
High flow and 1:1 mix	13.68	60	0.1	2.9	0.0	19	5.2	1.9	1.4	0.5
Low flow and 1:1 mix	0.385	533	4.0	2.1	1.9	183	2.9	13.7	4.2	0.6

Cement Creek water quality after bulkhead installation:	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
High flow and 4:1 mix	1.0	0.7	2.4	0.19	0.02	0.02
Low flow and 4:1 mix	0.5	5.3	7.3	0.30	0.24	0.03
High flow and 1:1 mix	1.0	0.7	2.5	0.19	0.03	0.02
Low flow and 1:1 mix	0.5	5.3	11.1	0.30	0.32	0.04

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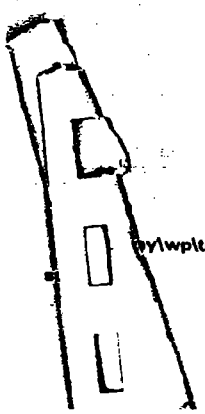
APPENDIX D

Petrographic Data from Proposed Bulkhead Sites



core. The fracture is old, but quite open with six obvious voids as much as 10mm long by 2 mm wide.

This core is <u>not</u> typical in that is also contains numerous open voids not associated with any fracture. These voids are as large as 2mm in diameter. The voids are generally within 15mm of the open fracture.

A tight, hard to distinguish fracture contains one void 2mm long and ½mm wide. No blast damage.

<u>F-Level Brennaman, South Rib</u>
This core is crossed diagonally by 4 old fractures. These fractures contain numerous open vugs up to 6mm long and 2mm wide. In addition, there are scattered open vugs up to 2mm in diameter which are not associated with fractures. There is not blast damage.

<u>Terry Tunnel (F-Level), Back</u>
Core is crossed diagonally by an open, fresh looking fracture which looks very much like recent (blast?) damage. Otherwise the rock appears very tight.

<u>Terry Tunnel (F-Level), North Rib</u>
Core shows no fractures whatsoever. Rock contains disseminated pyrite (less than 1mm across) and numerous phenocrysts up to 4mm.

<u>Terry Tunnel (F-Level), South Rib</u>
Top 15mm of core is a vein of white mineral with one open void 4mm across.

Core is crossed by 2 old looking fractures which contain white mineral. No blast damage is evident.

The core is about 11 inches long. The core has a large nick out of it 2½ inches from the bottom. A fresh looking fracture comes off of this nick and goes directly across the core following a veinlet of white mineral.

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American Tunnel, Back

This core has parts of 2 fractures crossing it. Neither fracture is positioned so as to have a major effect on a permeability test. The fractures appear old, but contain only a minimal amount of white mineral. The rock appears quite tight otherwise.

American Tunnel, North Rib

The rock is essentially unfractured. A very thin, tight veinlet of white mineral crosses the core diagonally. A slightly more open looking fracture exists near the top of the core, but should not affect the permeability test.

The rock appears very tight. It contains disseminated pyrite and obvious light phenocrysts up to 3mm long.

American Tunnel, South Rib

The core is split in half (lengthwise) by an obvious, fresh-looking fracture. The fracture appears open along its entire length and it is surprising the core doesn't fall apart. This fracture could well be blast damage.

Tight mineralized veinlets cross the core at a shallow angle. These are old and appear sealed.

This core contains more sulfides than the other cores, with pyrite blebs as large as 3mm across.

TABLE 1
SUMMARY OF ROCK PROPERTIES RELATED TO DURABILITY IN ACID WATERS

Sample No.	Location	Rock Type	Alteration	% Altered (non-Q)	Veins or Fractures				
					%	V or F	Spac-ing/mm	Thick-ness	Soluble Minerals
10	T.T., T-13	Andes Por.	Prop	48	tr	F	0.04*	0.8 mm	0%
11	T.T., T-15 + 300' to portal.	Andes Por.	Prop	33	3	V	0.10	1.2 mm	90%

LEGEND
* = Veinlets/mm
A.T. = American Tunnel
Andes = Andesite
B.V. = Brennaman Vein
Bx = Breccia
Carb = Carbonate
F = Fractures
L = Left
Ph = Phyllic
Por. = Porphyry
Prop = Propylitic
R = Right
T.T. = Terry Tunnel
V = Veins

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PETROGRAPHIC DESCRIPTIONS

SH-10; Moderate Propylitically Altered Andesite Porphyry.

Andesite (99+%):

Phenos (68%);

58% Plagioclase (Pl)	0.2-2.6mm	Subangular tabular crystals. Tr-55% replaced with patches of epidote (Ep) ± chlorite (Chl) ± carbonate (Car) ± magnetite (Mt). Cores of largest phenos totally replaced.
10% Ferromags	0.2-3.0mm	Sub-euhedral relict crystals. 100% replaced with Chl > Ep (on edges) > leucoxene or to Ep = Car > leucoxene > Chl > pyrite (Py).

Porphyroblasts (2%);

2% Pyrite (Py)	<0.02-0.3mm	Cubic euhedra scattered throughout groundmass and phenos. Predominately replaced by leucoxene >> hematite. Also leucoxene as very fine-grained particles in turbid, occasionally euhedral 1u to 0.25mm patches.

Groundmass (30%);

15% Feldspar	0.02-0.2mm	Subhedral tabular crystals tr-50% replaced by Ep in patches. Turbid due to incipient alteration to very fine-grained mineral inclusions and pores. Predominately plagioclase (Pl).
10% Chlorite (Chl)	1u-0.2mm	Green flakes to masses interstitial to Pl and replacing small relict ferromags in groundmass. Pennine.
5% Epidote (Ep)	1u-0.2mm	Subhedra scattered through Pl.

Veinlet (tr):

0.04mm thick	The only veinlet seen in thin section is Q filled, annealed, indistinct and discontinuous.

Fractures (tr):

See below.

This rock is generally cluody in thin section (t.s.) due to abundant secondary alteration pores. Magic marker was absorbed up to 0.4mm depth on epidote-lined fracture surfaces.

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SH-11; Propylitic-Altered Andesite Porphyry.

Andesite (97%):		
Phenos (12%);		
10% Feldspar (F)	0.6-3mm	Subhedra. 10-100% replaced by Car >> sericite (Ser) + Ep + Py.
2% Ferromag	0.6-1.4mm	Indistinct relict anhedra. 100% replaced by Chl + Py + Ep.
Groundmass (82%);		
77% Plagioclase	0.05-0.6mm	Un-oriented tabular subhedra contain abundant inclusions of alteration minerals listed below.
15% Chlorite	<0.1mm	In polycrystalline patches replacing ferromags and interstitial to Pl.
5% Epidote	1u-0.25mm	Predominately coarser tabular subhedra in clumps in small Pl and ferromags.
3% Muscovite	<20u	Flakes disseminated in Pl.
tr Apatite	0.04-0.2mm long	Scattered prisms.
tr Hematite (Ht)	<3u	As stain and clusters of flakes in rare patches.
tr Leucoxene	<10u	Grains in small clusters throughout groundmass.
Porphyroblasts (3%);		
3% Pyrite	0.04-0.6mm	Cubes in phenos and groundmass. Concentrated in ferromag phenos.
Veins and Veinlets (3%):		
	0.04-1.2mm	In many directions and commonly cross. Early, type A is Ep-filled. Later, type B are thin and contain Q > Ep. Type C is thick, linear, appears last, is offset and contains Car > Py + Q + Ep.

The total Car content of the rock excluding veins is estimated to be 5% and is in altered Pl phenos.

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APPENDIX E

Acid-Generation Testing of Secondary Mineral Crusts

McCLELLAND LABORATORIES, INC.

1016 Greg Street, Sparks, Nevada 89431 702 / 356-1300
FAX 702 / 356-8917

Report
on
Acid Generation Potential - Brenneman Samples
MLI Job No. 1893
February 11, 1993

for

Mr. Mark Stock
Simon Hydro-Search
5250 S. Virginia Street, Suite 280
Reno, NV 89502

SUMMARY

A total of six samples were submitted for paste pH measurement and special short term acid generation potential evaluation.

Paste pH for samples 3, 4, and 5 were low at pH 2.49, 3.11, and 3.56, respectively. This data would indicate a potential for acid production. However, it is thought that low paste pH was a function of acid salts contained in the solution phase of the moist samples, and not a function of the solids producing acid. Paste pH for samples 1, 2, and 6 was 4.62, 6.10, and 6.50, respectively.

Special acid generation potential scoping tests were conducted on five of the six samples. An insufficient quantity of sample six was available for evaluation. The data correlated well with paste pH data and indicated that acid pH encountered early in the cycle was a result of acid salts in residual moisture when the samples were taken. Slurry pH remained fairly constant after two hours, and demonstrates that the solids did not produce acid during the term of the test.

SAMPLE PREPARATION AND PASTE pH MEASUREMENTS

Samples were dry upon receipt. Each sample was weighed, and was subsequently pulverized in a mortar and pestle to a nominal 10 mesh feed size. Samples were blended and split to obtain appropriate quantities of sample for paste pH measurement and acid generation tests. Samples for paste pH were submitted to Chemax

Laboratories.

A sample cross-reference is provided in Table 1. Paste pH results are shown in Table 2. The Chemax Laboratories paste pH report sheet is provided in the Appendix to this report.

Table 1. - Sample Cross-Reference, Brenneman Samples

Sample Number	Description
1	F-Level, 100' East of bulkhead site, local sulfates
2	Brown-black mud flowstone, localized, 100' Inby of bulkhead site
3	B-Level, proposed bulkhead site, localized shot flowstone, 2 x 6 foot zone
4	B-Level, proposed bulkhead, 1/4" thick local deposit, brown flowstone
5	B-Level, Washington Vein near Washington vertical shaft - wall scrapings 1/16" thick
6	D-Level, wall scrape, 2700 stope, localized flowstone

Table 2. - Paste pH Results, Brenneman Samples

Sample Number	Paste pH, sp
1	4.62
2	6.10
3	2.49
4	3.11
5	3.56
6	6.50

SCOPING ACID GENERATION TEST PROCEDURE AND RESULTS

Scoping bottle roll acid generation potential tests were conducted on samples 1 through 5 to empirically determine the potential of the solids to produce acid.

Tests were conducted by contacting 5 g of solids with 500 ml of stock solution for 24 hours. Each slurry was continuously agitated by rolling in a zero head space bottle. Slurry pH was measured at 2, 4, 6, 8, 12, and 24 hours.

TABLE A–4

AMERICAN TUNNEL REFERENCE WATER
After Equilibration to Atmosphere and Precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	*Concentration mol/L*	*mg/L*	*Dominant Species*
SO_4--	9.644E-03	926	SO_4--
CO_3--	5.66E-04	33.9	HCO_3-
Cl-	1.412E-06	0.05	Cl-
F-	5.856E-05	1.11	F-
Ca++	8.396E-03	337	Ca++
Mg++	1.660E-04	4.04	Mg++
Na+	1.303E-04	3.00	Na+
Al+++	6.181E-09	ND	$Al(OH)_3$ aq
K+	1.281E-06	0.05	K+
H_4SiO_4	1.238E-07	ND	H_4SiO_4
Fe+++	2.486E-15	ND	$Fe(OH)_2$+
Mn++	2.619E-16	ND	Mn++
Zn++	1.493E-05	0.97	Zn++
Sr++	4.321E-05	3.79	Sr++
Cd++	5.344E-08	0.006	Cd++
Pb++	1.208E-07	0.025	$PbCO_3$ aq
pH	7.87		
pE	13.81		

Precipitated Minerals:	*moles precipitated per liter of solution*	*mg precipitated per liter of solution*	*Minerals near saturation:*	*S.I.*
Calcite	1.91E-03	191.171	Gypsum	-0.04
Pyrolusite	1.47E-04	12.780	Anhydrite	-0.38
$ZnSiO_3$	6.17E-05	8.728	Celestite	-0.60
Fluorite	4.90E-05	3.826	Cerussite	-0.99
Hematite	2.47E-05	3.944	Strontianite	-1.33
Diaspore	2.23E-05	1.338	Smithsonite	-1.39
Otavite	3.03E-07	0.052		

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Table A–5. Water analyses from shallower portions of the American Tunnel

Location	Date	Source	Flow MGD	Field pH	Field Conduct	Field Temp deg–C	Lab pH	Lab Conduct	TDS	TSS
AT–3450	07/23/92	ditch	1.41	6.67	1900	12.9	6.36	1830	1660	48
Fault–1	03/05/91	seep		5.90			2.45	3030	2560	42
Fault–2	03/05/91	seep		6.05			2.49	3440	2890	46
AT–2700	07/23/92	ditch	1.90	6.43	1980	12.1	4.77	1820	1730	88
AT–2400	07/23/92	ditch	2.06	6.36	1990	12.1	4.7	1860	1740	90
AT–portal	07/23/92	flume	2.20	6.36	1930	11.7	5.18	1880	1720	84
AT–portal	01/31/92	flume	3.17	6.60	1780	11.5	5.78	1920	1750	67

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

					Na	Mg	Sr	Al	K	Si
				379.0	7.6	16.3	8.68	0.5	1.40	
			0.50	42.5	13.6	161.0	5.59	12.8	1.50	
			6.13	13.9	9.2	21.7	5.89	22.3	1.69	
		6.46	<.10	380.0	7.4	16.3	6.73	1.9	0.39	
	2.44	6.46	0.82	391.0	7.4	19.3	6.46	1.9	1.17	
	1300	7.93	5.94	1.03	385.0	7.8	19.3	6.49	1.8	0.39
A1–portal	1230	15.90	5.04	1.75	496.0	7.0	12.7	8.48	0.9	

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

Location	Metals									
	Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)
AT–3450	0.3		26.0		21.2		<.01		0.08	
Fault–1	360.0	344.0	101.0	91.4	62.4	47.08	<.005	0.21	0.03	0.06
Fault–2	537.0	531.0	151.0	132.6	92.1	70.1	0.43	0.59	0.09	0.11
AT–2700	15.0		28.8		20.9		<.01		0.07	
AT–2400	5.6		30.5		20.3		<.01		0.06	
AT–portal	10.5	36.2	25.7	29.2	18.7	20.6	<.01	0.05	0.07	0.07
AT–portal		39.7	16.1	18.6	8.1	10.3	0.03	0.05	0.02	0.03

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Table A–5. Water analyses from shallower portions of the American Tunnel, Con't.

Location	Metals (con't.) Copper (Diss)	Copper (Total)	Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
AT–3450	0.18		<.001		<.005	0.12	0.13	<.05	0.005	<.01
Fault–1	<.01	0.34	<.001		<.005	<.01	<.02	<.05	<.005	<.01
Fault–2	<.01	0.03	<.001		<.005	<.01	<.02	<.05	<.005	<.01
AT–2700	0.33		<.001		<.005	0.13	0.16	<.05	<.005	<.01
AT–2400	0.29		<.001		<.005	0.16	0.14	<.05	<.005	<.01
AT–portal	0.23	0.82	<.001	<.001	<.005	0.15	0.17	<.05	<.005	<.01
AT–portal	0.04	0.07	<.002	<.002	<.005	<.01	<.02	0.12	<.005	<.01

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TABLE A–6

AMERICAN TUNNEL REFERENCE WATER

CO_2 flashed, calcite precipitated, then equilibrated with the atmosphere and again precipitated

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4––	9.644E–03	926	SO_4––
CO_3––	1.042E–04	6.25	HCO_3–
Cl–	1.412E–06	0.05	Cl–
F–	5.539E–05	1.05	F–
Ca++	9.445E–03	379	Ca++
Mg++	1.660E–04	4.04	Mg++
Na+	1.303E–04	3.00	Na+
Al+++	5.480E–09	ND	$Al(OH)_3$ aq
K+	1.281E–06	0.05	K+
H_4SiO_4	8.160E–07	ND	H_4SiO_4
Fe+++	7.112E–15	ND	$Fe(OH)_2$+
Mn++	9.213E–15	ND	Mn++
Zn++	7.085E–05	4.63	Zn++
Sr++	4.321E–05	3.79	Sr++
Cd++	3.564E–07	0.04	Cd++
Pb++	1.208E–07	0.025	$PbSO_4$ aq
pH	7.09		
pE	14.56		

Precipitated Minerals:	moles	mg	Minerals near saturation:	S.I.
Calcite *	8.515E–04	85.23	Gypsum	–0.01
Pyrolusite	1.473E–04	12.81	Anhydrite	–0.34
Ca–Nontronite	1.581E–05	6.71	Mg–Nontronite	–0.59
Fluorite	5.061E–05	3.95	Celestite	–0.62
Hematite	8.845E–06	1.41	Calcite	–1.50
Diaspore	1.888E–05	1.13	Otavite	–0.68
$ZnSiO_3$	2.934E–06	0.42	Cerussite	–1.81
			Smithsonite	–2.21
			Strontianite	–2.89

* precipitated in earlier step

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Table A–7. Water analyses from the Terry Tunnel

Location	Date	Source	Flow MGD	Field pH	Field Conduct	Field Temp deg–C	Lab pH	Lab Conduct	TDS	TSS
Influent	06/11/91	ditch	1.30	5.60		10.0	5.33	528	359	92
Influent	06/17/91	ditch	1.80	4.40		9.9	4.2	587	426	166
Influent	07/11/91	ditch	0.33	4.10			3.32	933	726	54

Location	Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Sr	Al	K	Si
Influent	264	3.05	2.37	1.42	55.7	1.5	33.9	0.56	0.9	1.14	
Influent	300	0.00	3.38	5.31	117.0	2.2	0.1	0.61	1.5	1.73	
Influent	544	0.00	5.56	0.30	160.0	1.7	19.0	0.98	3.2	1.20	

Location	Metals Iron (Diss)	Iron (Total)	Mn (Diss)	Mn (Total)	Zinc (Diss)	Zinc (Total)	Lead (Diss)	Lead (Total)	Cadmium (Diss)	Cadmium (Total)	Copper (Diss)	Copper (Total)
Influent	0.1		29.1		20.1	20.41	0.06	1.00	0.09	0.06	1.43	1.83
Influent	0.7		37.4		25.3		0.06		0.02		2.77	
Influent	4.1	13.2	76.8	77.8	47.3	47.6	0.88	1.05	0.19	0.19	5.05	5.11

Location	Metals (con't.) Mercury (Diss)	Mercury (Total)	Arsenic (Diss)	Boron (Diss)	Chromium (Diss)	Gold (Diss)	Selenium (Diss)	Silver (Diss)
Influent	<.0002	<.0002	<.002	<.05	<.02	<.05	<.002	<.01
Influent	<.0002		<.002	<.01	<.02	<.05	<.002	<.01
Influent	<.0002	<.0002	0.008	0.08	<.02	<.05	<.002	<.01

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able A–8. Terry Tunnel water equilibrated to atmospheric gas concentrations (This table gives the results of MINTEQA2 modeling.)

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	7.9	atmos equil	CO_3^{--}	H_2CO_3 aq
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF^{++}
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	$Fe(OH)_2^+$
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^{++}
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	Pb^{++}
pH	3.70	atmos equil	H^+	
pE	18.58	atmos equil	e^-	MnO_4^-

Mineral saturation indices

Sulfates:		Fluorite	−1.39
Strontianite	18.28 to 10.97		
Quartz	0.06	Oxides/hydroxides:	
		Hematite	13.22
		Pyrolusite	4.69
	−0.48	Goethite	4.15
	−0.50	Magnetite	1.12
	−0.89	Manganite	−0.04
	−1.36	Diaspore	−3.55

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Table A–9. Terry Tunnel water with restored inorganic carbon equilibrated to atmosphere
(This table gives the results of MINTEQA2 modeling.)

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	6.41	mineral equil	CO_3^{--}	HCO_3^-
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF_3 aq
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	$Fe(OH)_2^+$
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^{++}
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	$PbSO_4$ aq
pH	7.01	atmos equil		
pE	15.27	atmos equil		MnO_4^-

Mineral saturation indices

Silicates:		Oxides/hydroxides:	
Nontronites	28.89 to 21.58	Hematite	20.36
Leonhardite	14.77	Magnetite	11.83
Muscovite	8.96	Pyrolusite	11.30
Montmorillonite	8.29	Goethite	7.72
Pyrophyllite	8.08	Manganite	6.57
Kaolinite	7.50	Diaspore	3.65
Microcline	0.18	Tenorite	0.87
Quartz	0.06		
		Carbonates:	
Sulfates:		Malachite	1.23
Brochantite	5.06	Otavite	−0.11
Gypsum	−0.47	Cerussite	−0.17
Anglesite	−0.58	Rhodochrosite	−0.53
Anhydrite	−0.89	Smithsonite	−1.38
Celestite	−1.35	Calcite	−2.00
Fluorite	−0.17		

Table A–10. Terry Tunnel reference water

Analyte	Concentration mg/L	Source	MINTEQA2 Component	Dominant Species
Sulfate	544	analysis	HS^-/SO_4^{--}	SO_4^{--}
Bicarbonate	6.41	mineral equil	CO_3^{--}	HCO_3^-
Chloride	0.3	analysis	Cl^-	Cl^-
Fluoride	5.56	analysis	F^-	AlF_3 aq
Calcium	160	analysis	Ca^{++}	Ca^{++}
Magnesium	19	analysis	Mg^{++}	Mg^{++}
Sodium	1.7	analysis	Na^+	Na^+
Aluminum	3.2	analysis	Al^{+++}	AlF_3 aq
Potassium	1.2	analysis	K^+	K^+
Silica	5.3	mineral equil	H_4SiO_4	H_4SiO_4
Iron	13.24	analysis(total)	Fe^{++}/Fe^{+++}	Fe^{++}
Manganese	77.78	analysis(total)	Mn^{++}/Mn^{+++}	Mn^{++}
Copper	5.11	analysis(total)	Cu^+/Cu^{++}	Cu^+
Zinc	47.6	analysis(total)	Zn^{++}	Zn^{++}
Strontium	0.98	analysis(total)	Sr^{++}	Sr^{++}
Cadmium	0.19	analysis(total)	Cd^{++}	Cd^{++}
Lead	1.05	analysis(total)	Pb^{++}	Pb^{++}
pH	7.01	atmos equil	H^+	HCO_3^-
pE	−1.50	mineral equil	e^-	MnO_4^-

Mineral saturation indices

Silicates:		Oxides/hydroxides:	
Nontronites	15.11 to 7.80	Magnetite	7.93
Leonhardite	14.77	Cuprite	7.56
Muscovite	8.96	Hematite	6.58
Pyrophyllite	8.08	Diaspore	3.65
Montmorillonite	6.78	Gibbsite	1.84
Kaolinite	7.51	Goethite	0.83
Microcline	0.18		
Quartz	0.06		
		Carbonates:	
Sulfates:		Otavite	−0.11
Gypsum	−0.48	Cerussite	−0.17
Anglesite	−0.58	Rhodochrosite	−0.53
Anhydrite	−0.89	Smithsonite	−1.38
Celestite	−1.35	Calcite	−2.00
Fluorite	0.51	Sulfides:	
		Chalcocite	18.78
		Chalcopyrite	4.83
		Greenockite	0.60
Metallic Copper	6.96	Galena	0.24
		Sphalerite	−1.45
		Pyrite	−7.87

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Table A–11.
1:4 Mix of Terry and American Tunnels Water
Water mix with and without precipitation in flooded mine
(This table gives the results of MINTEQA2 modeling.)

	Mixed Waters no precipitation mg/L	*Mixed Waters precipitated mg/L*	*Relative Amount precipitated %*
SO_4--	850	841	1.1
HCO_3-	123	106	13.4
Cl-	0.10	0.10	0.0
F-	3.49	1.00	71.4
Ca++	364	361	0.7
Mg++	7.0	7.0	0.0
Al+++	1.12	ND	100.0
Na+	2.74	2.74	0.0
K+	0.28	0.28	0.0
H_4SiO	5.81	0.06	99.0
Mn	22.0	7.07	67.8
Zn++	13.5	3.63	73.1
Fe	4.58	ND	99.9
Cu	1.02	ND	100.0
Sr++	3.22	3.22	0.0
Pb++	0.23	0.01	96.3
Cd++	0.07	ND	99.8
pH	7.06	7.32	
pE	–2.2	–2.2	

Minerals Precipitated:	*moles precipitated per liter of solution*	*mg precipitated per liter of solution*
Rhodochrosite	2.72E–04	31.3
Sphalerite	9.15E–05	8.9
$ZnSiO_3$	5.99E–05	8.5
Hematite	3.64E–05	5.9
Fluorite	6.60E–05	5.2
Diaspore	4.16E–05	2.5
Cuprous ferrite	9.15E–06	1.5
Chalcocite	3.47E–06	0.6
Galena	1.07E–06	0.3
Greenockite	6.22E–07	0.1

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Table A–12.
1:1 Mix of Terry and American Tunnels Water
Water mix with and without precipitation in flooded mine
(This table gives the result of MINTEQA2 modeling.)

	Mixed Waters no precipitation mg/L	*Mixed Waters precipitated mg/L*	*Relative Amount precipitated %*
SO_4--	735	723	1.6
HCO_3-	79.5	61.2	23.0
Cl-	0.18	0.18	0.0
F-	4.27	1.09	74.5
Ca++	287	284	1.2
Mg++	11.5	11.5	0.0
Al+++	1.90	ND	100.0
Na+	2.35	2.35	0.0
K+	0.63	0.63	0.0
H_4SiO	5.62	0.05	99.0
Mn	43.0	26.5	38.4
Zn++	26.3	14.9	43.3
Fe	7.83	0.01	99.9
Cu	2.55	ND	100.0
Sr++	2.38	2.38	0.0
Pb++	0.54	0.02	97.1
Cd++	0.12	ND	99.5
pH	6.98	7.00	
pE	−1.8	−1.8	

Minerals Precipitated:	*moles precipitated per liter of solution*	*mg precipitated per liter of solution*
Rhodochrosite	3.00E−04	34.4
Sphalerite	1.17E−04	11.3
$ZnSiO_3$	5.79E−05	8.2
Hematite	5.00E−05	8.0
Fluorite	8.39E−05	6.6
Cuprous ferrite	4.02E−05	6.1
Diaspore	7.05E−05	4.2
Galena	2.52E−06	0.6
Greenockite	1.02E−06	0.1

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Table A–13.
Terry Tunnel reference water after equilibration to atmosphere and precipitation
(THESE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	5.668E-03	544	SO_4--
CO_3--	1.288E-05	0.77	H_2CO_3 aq
Cl-	8.469E-06	0.30	Cl-
F-	2.929E-04	5.56	AlF_3 aq
Ca++	3.993E-03	160	Ca++
Mg++	7.821E-04	19.0	Mg++
Na+	7.401E-05	1.70	Na+
Al+++	1.142E-04	3.08	AlF_3 aq
K+	3.072E-05	1.20	K+
H_4SiO_4	6.028E-06	ND	H_4SiO_4
Fe+++	5.626E-08	ND	FeF++
Mn++	4.448E-06	ND	Mn++
Cu++	8.040E-05	5.11	Cu++
Zn++	7.288E-04	47.6	Zn++
Sr++	1.119E-05	0.98	Sr++
Cd++	1.692E-06	0.19	Cd++
Pb++	5.072E-06	1.05	Pb++
pH	2.60		
pE	19.68		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	1.41E-03	122.93	Mg-Nontronite	-0.42
Hematite	1.05E-04	16.78	Gypsum	-0.48
Ca-Nontronite	1.34E-05	5.72	Anglesite	-0.50
			Anhydrite	-0.89
			Quartz	-0.90
			Fluorite	-1.11
			Celestite	-1.36

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Table A–14.
4:1 Mix (American Tunnel to Terry Tunnel) of reference waters after equilibration to atmosphere and precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	8.849E-03	850	SO_4--
CO_3-	5.566E-04	33.4	HCO_3-
Cl-	2.823E-06	0.10	Cl-
F-	5.238E-05	1.00	F-
Ca++	9.013E-03	361	Ca++
Mg++	2.892E-04	7.03	Mg++
Na+	1.190E-04	2.74	Na+
Al+++	8.842E-09	ND	$Al(OH)_3$ aq
K+	7.169E-06	0.28	K+
H_4SiO_4	2.387E-08	ND	H_4SiO_4
Fe+++	3.561E-15	ND	$Fe(OH)_2$+
Mn++	2.464E-16	ND	Mn++
Cu++	4.063E-06	0.26	$Cu(OH)_2$ aq
Zn++	1.373E-04	8.98	Zn++
Sr++	3.681E-05	3.23	Sr++
Cd++	6.526E-08	0.01	Cd++
Pb++	8.555E-07	0.18	$PbCO_3$ aq
pH	7.82		
pE	14.18		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	4.01E-04	34.88	Gypsum	-0.04
$ZnSiO_3$	6.04E-05	8.55	Calcite	-0.07
Hematite	4.10E-05	6.55	Cerussite	-0.11
Fluorite	6.60E-05	5.15	Brochantite	-0.42
Tenorite	1.20E-05	5.10	Anhydrite	-0.42
ZnO (Active)	9.37E-06	4.24	Smithsonite	-0.55
Diaspore	4.16E-05	2.49	Malachite	-0.64
Otavite	5.58E-07	0.10	Celestite	-0.72
Plattnerite	2.55E-07	0.06		

Table A–15.
1:1 Mix of American Tunnel and Terry Tunnel reference waters after equilibration to atmosphere and precipitation
(THESE ARE VALUES GENERATED BY THE MODEL)

MINTEQA2 Component	Concentration mol/L	mg/L	Dominant Species
SO_4--	7.647E-03	735	SO_4--
CO_3--	2.320E-04	13.9	HCO_3-
Cl-	4.941E-06	0.18	Cl-
F-	5.713E-05	1.09	F-
Ca++	7.089E-03	284	Ca++
Mg++	4.741E-04	11.5	Mg++
Na+	1.022E-04	2.35	Na+
Al+++	8.521E-09	ND	$Al(OH)_3$ aq
K+	1.600E-05	0.63	K+
H_4SiO_4	5.025E-08	ND	H_4SiO_4
Fe+++	5.423E-15	ND	$Fe(OH)_2$+
Mn++	1.410E-15	ND	Mn++
Cu++	3.832E-06	0.24	$Cu(OH)_2$ aq
Zn++	3.443E-04	22.5	Zn++
Sr++	2.720E-05	2.38	Sr++
Cd++	3.485E-07	0.04	Cd++
Pb++	2.147E-06	0.44	$PbCO_3$ aq
pH	7.43		
pE	14.57		

Precipitated Minerals:	moles precipitated per liter of solution	mg precipitated per liter of solution	Minerals near saturation:	S.I.
Pyrolusite	7.82E-04	68.00	Tenorite	-0.08
Hematite	7.01E-05	11.20	Gypsum	-0.16
$ZnSiO_3$	5.84E-05	8.27	Anhydrite	-0.54
Fluorite	8.40E-05	6.56	Malachite	-0.80
Diaspore	7.05E-05	4.23	Celestite	-0.87
Brochantite	9.09E-06	3.86	Smithsonite	-0.87
Otavite	6.76E-07	0.12	Calcite	-0.94
Cerussite	4.49E-07	0.12		

Table A–16. Comparison of modeled discharge water with chemistry of Cement Creek

Date	Source	Flow MGD	Field pH	Field Temp deg. C	Lab pH	Major Anions Sulfate	Bicarb	Fluoride	Chloride
05/31/89	Cement Creek	15.67	3.9	12.0	4.1	50		4.8	
07/02/87	Cement Creek	11.47	3.9	8.8	4.2	60	0.0	0.4	0.0
	4:1 Spring Wtr	0.11	7.8	9.0		850	33.4	1.0	0.1
	1:1 Spring Wtr	0.11	7.4	9.0		735	13.9	1.1	0.2
03/29/91	Cement Creek	0.32	4.2	5.0	4.5	462	0.0	2.2	3.1
02/11/91	Cement Creek	0.23	5.7	1.9	3.5	439	0.0	3.1	2.0

Date	Source	Major Cations Ca	Na	Mg	Al	K	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
05/31/89	Cement Creek	17	8.4	0.2	1.8	0.9	1.2	0.5	1.4	0.24	0.04	0.01
07/02/87	Cement Creek	16	1.0	4.0	0.8	0.0	0.7	1.0	3.8	0.13	ND	0.03
	4:1 Spring Wtr	361	2.7	7.0	0.0	0.3	0.0	0.0	9.0	0.26	0.18	0.01
	1:1 Spring Wtr	284	2.4	11.5	0.0	0.6	0.0	0.0	22.5	0.24	0.44	0.04
03/29/91	Cement Creek	147	2.3	14.1	5.2	0.6	0.3	6.8	6.0	0.26	0.25	0.02
02/11/91	Cement Creek	135	4.1	15.2	6.7	0.7	1.1	8.3	7.4	0.40	0.29	0.07

Cement Creek water quality after bulkhead installation:		Major Anions Sulfate	Bicarb	Fluoride	Chloride	Major Cations Ca	Na	Mg	Al	K
High flow and 4:1 mix	13.68	61	0.3	2.9	0.0	19	5.3	1.8	1.4	0.5
Low flow and 4:1 mix	0.385	566	9.5	2.1	1.9	205	3.0	12.4	4.2	0.5
High flow and 1:1 mix	13.68	60	0.1	2.9	0.0	19	5.2	1.9	1.4	0.5
Low flow and 1:1 mix	0.385	533	4.0	2.1	1.9	183	2.9	13.7	4.2	0.6

Cement Creek water quality after bulkhead installation:	Metals Iron (Diss)	Mn (Diss)	Zinc (Diss)	Copper (Diss)	Lead (Diss)	Cadmium (Diss)
High flow and 4:1 mix	1.0	0.7	2.4	0.19	0.02	0.02
Low flow and 4:1 mix	0.5	5.3	7.3	0.30	0.24	0.03
High flow and 1:1 mix	1.0	0.7	2.5	0.19	0.03	0.02
Low flow and 1:1 mix	0.5	5.3	11.1	0.30	0.32	0.04

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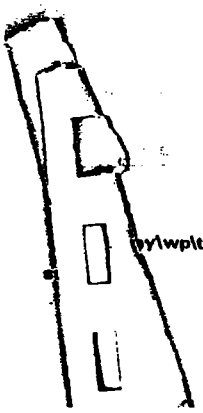
APPENDIX D

Petrographic Data from Proposed Bulkhead Sites



core. The fracture is old, but quite open with six obvious voids as much as 10mm long by 2 mm wide.

This core is <u>not</u> typical in that is also contains numerous open voids not associated with any fracture. These voids are as large as 2mm in diameter. The voids are generally within 15mm of the open fracture.

A tight, hard to distinguish fracture contains one void 2mm long and ½mm wide. No blast damage.

<u>F-Level Brennaman, South Rib</u>
This core is crossed diagonally by 4 old fractures. These fractures contain numerous open vugs up to 6mm long and 2mm wide. In addition, there are scattered open vugs up to 2mm in diameter which are not associated with fractures. There is not blast damage.

<u>Terry Tunnel (F-Level), Back</u>
Core is crossed diagonally by an open, fresh looking fracture which looks very much like recent (blast?) damage. Otherwise the rock appears very tight.

<u>Terry Tunnel (F-Level), North Rib</u>
Core shows no fractures whatsoever. Rock contains disseminated pyrite (less than 1mm across) and numerous phenocrysts up to 4mm.

<u>Terry Tunnel (F-Level), South Rib</u>
Top 15mm of core is a vein of white mineral with one open void 4mm across.

Core is crossed by 2 old looking fractures which contain white mineral. No blast damage is evident.

The core is about 11 inches long. The core has a large nick out of it 2½ inches from the bottom. A fresh looking fracture comes off of this nick and goes directly across the core following a veinlet of white mineral.

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American Tunnel, Back

This core has parts of 2 fractures crossing it. Neither fracture is positioned so as to have a major effect on a permeability test. The fractures appear old, but contain only a minimal amount of white mineral. The rock appears quite tight otherwise.

American Tunnel, North Rib

The rock is essentially unfractured. A very thin, tight veinlet of white mineral crosses the core diagonally. A slightly more open looking fracture exists near the top of the core, but should not affect the permeability test.

The rock appears very tight. It contains disseminated pyrite and obvious light phenocrysts up to 3mm long.

American Tunnel, South Rib

The core is split in half (lengthwise) by an obvious, fresh-looking fracture. The fracture appears open along its entire length and it is surprising the core doesn't fall apart. This fracture could well be blast damage.

Tight mineralized veinlets cross the core at a shallow angle. These are old and appear sealed.

This core contains more sulfides than the other cores, with pyrite blebs as large as 3mm across.

TABLE 1
SUMMARY OF ROCK PROPERTIES RELATED TO DURABILITY IN ACID WATERS

Sample No.	Location	Rock Type	Alteration	% Altered (non-Q)	Veins or Fractures				
					%	V or F	Spac-ing/mm	Thick-ness	Soluble Minerals
10	T.T., T-13	Andes Por.	Prop	48	tr	F	0.04*	0.8 mm	0%
11	T.T., T-15 + 300' to portal.	Andes Por.	Prop	33	3	V	0.10	1.2 mm	90%

LEGEND
* = Veinlets/mm
A.T. = American Tunnel
Andes = Andesite
B.V. = Brennaman Vein
Bx = Breccia
Carb = Carbonate
F = Fractures
L = Left
Ph = Phyllic
Por. = Porphyry
Prop = Propylitic
R = Right
T.T. = Terry Tunnel
V = Veins

ED_000552B_00064447-00172

PETROGRAPHIC DESCRIPTIONS

SH-10; Moderate Propylitically Altered Andesite Porphyry.

Andesite (99+%):

Phenos (68%);

58% Plagioclase (Pl)	0.2-2.6mm	Subangular tabular crystals. Tr-55% replaced with patches of epidote (Ep) ± chlorite (Chl) ± carbonate (Car) ± magnetite (Mt). Cores of largest phenos totally replaced.
10% Ferromags	0.2-3.0mm	Sub-euhedral relict crystals. 100% replaced with Chl > Ep (on edges) > leucoxene or to Ep = Car > leucoxene > Chl > pyrite (Py).

Porphyroblasts (2%);

2% Pyrite (Py)	<0.02-0.3mm	Cubic euhedra scattered throughout groundmass and phenos. Predominately replaced by leucoxene >> hematite. Also leucoxene as very fine-grained particles in turbid, occasionally euhedral 1u to 0.25mm patches.

Groundmass (30%);

15% Feldspar	0.02-0.2mm	Subhedral tabular crystals tr-50% replaced by Ep in patches. Turbid due to incipient alteration to very fine-grained mineral inclusions and pores. Predominately plagioclase (Pl).
10% Chlorite (Chl)	1u-0.2mm	Green flakes to masses interstitial to Pl and replacing small relict ferromags in groundmass. Pennine.
5% Epidote (Ep)	1u-0.2mm	Subhedra scattered through Pl.

Veinlet (tr):

0.04mm thick	The only veinlet seen in thin section is Q filled, annealed, indistinct and discontinuous.

Fractures (tr):

See below.

This rock is generally cluody in thin section (t.s.) due to abundant secondary alteration pores. Magic marker was absorbed up to 0.4mm depth on epidote-lined fracture surfaces.

1801589 ED_000552B_00064447-00173

SH-11; Propylitic-Altered Andesite Porphyry.

Andesite (97%):		
Phenos (12%);		
10% Feldspar (F)	0.6–3mm	Subhedra. 10–100% replaced by Car >> sericite (Ser) + Ep + Py.
2% Ferromag	0.6–1.4mm	Indistinct relict anhedra. 100% replaced by Chl + Py + Ep.
Groundmass (82%);		
77% Plagioclase	0.05–0.6mm	Un-oriented tabular subhedra contain abundant inclusions of alteration minerals listed below.
15% Chlorite	<0.1mm	In polycrystalline patches replacing ferromags and interstitial to Pl.
5% Epidote	1u–0.25mm	Predominately coarser tabular subhedra in clumps in small Pl and ferromags.
3% Muscovite	<20u	Flakes disseminated in Pl.
tr Apatite	0.04–0.2mm long	Scattered prisms.
tr Hematite (Ht)	<3u	As stain and clusters of flakes in rare patches.
tr Leucoxene	<10u	Grains in small clusters throughout groundmass.
Porphyroblasts (3%);		
3% Pyrite	0.04–0.6mm	Cubes in phenos and groundmass. Concentrated in ferromag phenos.
Veins and Veinlets (3%):		
	0.04–1.2mm	In many directions and commonly cross. Early, type A is Ep-filled. Later, type B are thin and contain Q > Ep. Type C is thick, linear, appears last, is offset and contains Car > Py + Q + Ep.

The total Car content of the rock excluding veins is estimated to be 5% and is in altered Pl phenos.

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APPENDIX E

Acid-Generation Testing of Secondary Mineral Crusts

McCLELLAND LABORATORIES, INC.

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Report
on
Acid Generation Potential - Brenneman Samples
MLI Job No. 1893
February 11, 1993

for

Mr. Mark Stock
Simon Hydro-Search
5250 S. Virginia Street, Suite 280
Reno, NV 89502

SUMMARY

A total of six samples were submitted for paste pH measurement and special short term acid generation potential evaluation.

Paste pH for samples 3, 4, and 5 were low at pH 2.49, 3.11, and 3.56, respectively. This data would indicate a potential for acid production. However, it is thought that low paste pH was a function of acid salts contained in the solution phase of the moist samples, and not a function of the solids producing acid. Paste pH for samples 1, 2, and 6 was 4.62, 6.10, and 6.50, respectively.

Special acid generation potential scoping tests were conducted on five of the six samples. An insufficient quantity of sample six was available for evaluation. The data correlated well with paste pH data and indicated that acid pH encountered early in the cycle was a result of acid salts in residual moisture when the samples were taken. Slurry pH remained fairly constant after two hours, and demonstrates that the solids did not produce acid during the term of the test.

SAMPLE PREPARATION AND PASTE pH MEASUREMENTS

Samples were dry upon receipt. Each sample was weighed, and was subsequently pulverized in a mortar and pestle to a nominal 10 mesh feed size. Samples were blended and split to obtain appropriate quantities of sample for paste pH measurement and acid generation tests. Samples for paste pH were submitted to Chemax

Laboratories.

A sample cross-reference is provided in Table 1. Paste pH results are shown in Table 2. The Chemax Laboratories paste pH report sheet is provided in the Appendix to this report.

Table 1. - Sample Cross-Reference, Brenneman Samples

Sample Number	Description
1	F-Level, 100' East of bulkhead site, local sulfates
2	Brown-black mud flowstone, localized, 100' Inby of bulkhead site
3	B-Level, proposed bulkhead site, localized shot flowstone, 2 x 6 foot zone
4	B-Level, proposed bulkhead, 1/4" thick local deposit, brown flowstone
5	B-Level, Washington Vein near Washington vertical shaft - wall scrapings 1/16" thick
6	D-Level, wall scrape, 2700 stope, localized flowstone

Table 2. - Paste pH Results, Brenneman Samples

Sample Number	Paste pH, sp
1	4.62
2	6.10
3	2.49
4	3.11
5	3.56
6	6.50

SCOPING ACID GENERATION TEST PROCEDURE AND RESULTS

Scoping bottle roll acid generation potential tests were conducted on samples 1 through 5 to empirically determine the potential of the solids to produce acid.

Tests were conducted by contacting 5 g of solids with 500 ml of stock solution for 24 hours. Each slurry was continuously agitated by rolling in a zero head space bottle. Slurry pH was measured at 2, 4, 6, 8, 12, and 24 hours.

The stock solution was prepared to simulate the buffering capacity of the mine site water by adding 0.0042 g $NaHCO_3$ per liter of deionized water. The pH of the deionized water before addition of $NaHCO_3$ was 5.4. The pH of the buffered stock solution 15 minutes after $NaHCO_3$ addition was 7.5.

The pH meter was standardized with pH 2, 4, and 7 buffer before each slurry pH measurement.

A control test was also performed to establish the pH drift of the stock solution. Procedures for the control test were exactly the same except that solids were not added to the stock solution.

Results from the scoping tests are shown in Table 3.

Table 3. - Scoping Acid Generation Potential Test Results
Brenneman Samples

	Slurry pH					
Sample	Sample Number					
Time, Hrs.	1	2	3	4	5	Control
2	6.65	6.00	3.00	3.65	5.60	7.30
4	6.50	5.90	2.90	3.55	5.70	7.40
6	6.50	5.95	2.80	3.50	5.75	7.30
8	6.65	5.90	2.80	3.50	5.70	7.30
12	6.65	6.05	2.80	3.50	5.80	7.30
24	6.60	6.05	2.75	3.45	5.70	7.10

Scoping test results show that initial decrease in slurry pH was likely caused by acid salts contained in the solution phase of the moist samples taken from the walls of the mine. Slurry pHs were fairly stable after two hours for all five samples, and indicates that the solids do not show a potential to produce acid. These data are consistent with paste pH data.

Gene E. McClelland
Metallurgist/President

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Addendum Report
on
Acid Generation Potential - Brenneman Samples
MLI Job No. 1893
March 11, 1993

for

Mr. Mark Stock
Simon Hydro-Search
5250 S. Virginia Street, Suite 280
Reno, NV 89502

SUMMARY

Initial results from the special acid generation potential tests conducted on five Brenneman samples indicated that samples 3 and 4 remained below pH 4.0 after 24 hours of contact with weakly buffered deionized water at a 100:1 solution to solids ratio. Additional tests were conducted on the original slurries of samples 3 and 4 using a 1,000:1 ratio to determine potential to produce acid.

Results show that at a 1,000:1 ratio sample 4 did not produce acid. Slurry pH increased 3.4 to 6.7 after 24 hours of contact with fresh buffered stock solution. The slurry pH for sample 3, at the 1,000:1 ratio, remained below pH 4.0. Slurry pH increased from 2.7 to 3.6 with 24 hours of contact with fresh buffered stock solution.

An additional test was conducted on the sample 3 slurry using a 10,000:1 solution to solids ratio. Slurry pH increased from 3.6 to 5.0 after 24 hours of contact with buffered stock solution at the 10,000:1 ratio.

SCOPING ACID GENERATION TEST PROCEDURES AND RESULTS

Slurries at the 100:1 ratio lay idle for 20 days after the initial 24 hour agitated acid generation tests were completed. After 20 days, slurries were agitated for 1 hour and slurry pHs were measured. Results comparing slurry pHs before and after 20 days without agitation are shown in Table 1.

Table 1. - Slurry pH Data, Brenneman Samples, 100:1 Ratio

Contact Time	Slurry pH Sample Number 1	2	3	4	5	Control
24 Hours	6.60	6.05	2.75	3.45	5.70	7.10
20 Days, idle	6.10	5.95	2.70	3.40	5.50	6.75

Slurry pHs remained stable even after 20 days of contact with solution at the 100:1 solution to solids ratio. These data indicate that none of the solids generate acid, even though slurry pHs for samples 3 and 4 remained below pH 4.

Samples 3 and 4 were selected for additional evaluation using a 1,000:1 solution to solids ratio. Initial slurries (100:1) were diluted with fresh buffered stock solution (0.0042 g/l $NaHNO_3$ in deionized water) to obtain a 1,000:1 solution to solids ratio. Test procedures were the same as described in MLI report data February 11, 1993, except that slurry pH was measured at 0, 12, and 24 hours. A total of 500 ml of initial slurry was mixed with 4.5 liters of fresh stock solution.

Results from the 1,000:1 ratio tests are provided in Table 2.

Table 2. - Scoping Acid Generation Potential Test Results
Brenneman Samples, 1,000:1 Ratio

Sample Time, hours	Slurry pH Sample Number 3	4
0	3.7	5.1
12	3.7	6.5
24	3.6	6.7

Results show that sample 4 did not generate acid. Slurry pH increased from 3.4 (100:1 ratio after 20 days) to 6.7 with 24 hours of contact with stock solution at the 1,000:1 ratio. Slurry pH for sample 3 increased from 2.70 (100:1, after 20 days) to 3.6. The one pH unit increase roughly corresponded to the additional 10 to 1 dilution ratio. The data does not, however, demonstrate that sample 3 solids produce acid while in contact with a weakly buffered deionized water solution.

An additional test was conducted on the sample 3 slurry using a 10,000:1 solution to solids ratio. The slurry from the 1,000:1 ratio was again diluted 10:1 with fresh stock solution by adding 500 ml of slurry to 4.5 liters of fresh stock solution. Results for the 10,000:1 ratio test are provided in Table 3.

Table 3. - Scoping Acid Generation Potential Test, Brenneman Sample 3, 10,000:1 Ratio

Sample Time, hours	Slurry pH
0	5.5
12	5.3
24	5.0

Results show that slurry pH decreased slightly with time, but at the 10,000:1 ratio, final pH was 5.0. Decrease in slurry pH can be attributed, in part, by the weak buffering capacity of the stock solution, and by contact with CO_2 in air. Stock solution pH decreased from 7.2 to 6.9 during the 24 hour period. That data does not demonstrate that decrease in pH was caused by acid produced by the solids.

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